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Engineering Design Process:
Creating and 3D Printing a Mechanical Toy

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Engineering Design Process:
Creating and 3D Printing a Mechanical Toy

by

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Report

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Dedication

In memory of "Tito", my beloved Mexican red head parrot pet (1985-2015) for the 30 years of unconditional love, loyalty, and friendship that will be kept forever in my heart, mind, and soul. ¡Tito, te amo!

Acknowledgements

First of all, I would like to thank God and my family for providing me with all the moral support that was needed in order to finish with this report. I would like to also thank the MASEE Program (Master of Arts in STEM in Education-Engineering) from UTeach*Engineering* Cohort 5 students, staff and faculty at the University of Texas at Austin, especially Dr. Richard Crawford for inspiring me to do this project on mechanical engineering, Dr. Anthony Petrosino for the enrichment in knowledge in education and learning, and Dr. Jill Marshall for overseeing my project along with Dr. Catherine Riegle-Crumb for her academic advising, encouragement, and support in the final steps of my project. Finally, I want to thank the Brownsville Early College High School in Brownsville, Texas for providing the facility and resources to conduct my research.

Abstract

Engineering Design Process:
Creating and 3D Printing a Mechanical Toy

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The University of Texas at Austin, 2016

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This report describes an activity that explores the Engineering Design Process through a research-based module intended to be implemented in a grade 9-12 science, technology, engineering and mathematics (STEM) classroom. Moreover, this study serves as a demonstration of the module's effectiveness in guiding end users through the Engineering Design Process using computer aided design (CAD) software, to design and fabricate a fully working 3D printed mechanical toy. The hypothesis of the research is that usage of the module makes an impact on students' proficiency with and understanding of the Engineering Design Process. Of the students enrolled in the Engineering Design and Presentation class (n=38) at the Brownsville Early College High School, a random sample (n=12) was selected for data collection purposes. Results showed that using the module increases students' understanding of and proficiency with the Engineering Design Process and Autodesk Inventor. Finally, this paper provides insights on future modifications of the module that could lead to a better learning tool for STEM education.

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Chapter 1: Introduction

Overview: As part of the MASEE Program at UT-Austin, I created a design challenge module for high school students in order for them to understand and discover the engineering design concepts through the development of a 3D printed mechanical toy. The module takes the student through a step-by-step self-paced and/or teacher-paced tutorial. It promotes creativity, discovery and do-it-yourself learning techniques that will help students learn the EDP, with the hope of implementing the acquired knowledge to design their own challenges and/or products while mastering the required objectives for the Engineering Design and Problem Solving curriculum as specified by the state of Texas.

Science, Technology, Engineering and Mathematics (STEM) education, problem solving skills, time management skills, high order thinking skills, and team work are words that educators hear often during workshops and trainings now more than ever. These are not only mere words, but they also represent a national educational investment in the attempt to "boost U.S. economic competitiveness by beefing up the STEM workforce" ("Delta Cost," n.d.). According to the National Academy of Engineering (NAE) and National Research Council (NRC) "…engineering education could result in improved student achievement in science and mathematics, increased awareness and interest in engineering, and increased level of technical literacy (Elam 35)." As a consequence, programs like *For Inspiration and Recognition of Science and Technology* (FIRST), FIRST Robotics Competition (FRC), VEX Robotics Competition and many others have expanded and foster the need and motivation for these practices through safe and friendly competition among teens nationwide ("Competition," n.d.; "Vision" n.d.). Students in such programs compete in challenges that require the use of the Engineering Design Process (EDP), and the use of computer aided design (CAD) software.

Additionally, participants in VEX, FIRST Tech Challenge (FTC), and FIRST LEGO® League can use Robot Virtual Worlds (RVW), a robot simulator created by Robomatter, Inc. (Pittsburgh, PA), that aids students in designing better programs ("Robot," n.d).

There are also CAD pre-modeled kits of parts available for FIRST Robotics Competition (FTC) and VEX Robotics, thanks to design and file sharing collaborations between robotics competition teams that practice "Gracious Professionalism" and "Coopertiton" (Gracious, n.d.), FIRST's ideas of helping and treating each other (teams, students, mentors, and communities) with kindness and respect, with the common goal of global learning and support to obtain win-win outcomes for everyone. With these pre-modeled parts, students can create assemblies and animations, and test their robots using popular CAD software programs (such as Autodesk Inventor (Autodesk, Inc., San Rafael, CA), PTC Creo (PTC, Needham, MA), and SOLIDWORKS (Dassault Systèmes SOLIDWORKS Corp, Waltham, MA) before building the robot itself. Such software is currently used in industry by engineers, but some, like Autodesk Inventor, have free home professional versions for students and teachers with a license that lasts up to three years ("CAD", n.d.). To keep our students in the vanguard for such competitions, we need to take advantage of available resources like *Engineer Your World's* Engineering Design Standard Process ("Course," n.d.), and the free educational Autodesk Inventor Professional 2014, to enable our students to understand some of the necessary STEM skills in an engaging hands-on way. To this end, an Engineering Design Process module has been created to illustrate step by step how to design and assemble a fully working mechanical toy that can be tested virtually before it is 3D printed. The module uses the same strategies that engineers use on a daily basis, and best of all, it is aligned with the Texas Essential Knowledge and Skills for Engineering Design and Problem Solving (Texas Education Agency, 2010). This module will train our students how to use the

Engineering Design Process properly with the intention that they can use Engineering Design Process strategies when they create their own products, or robots for their FIRST or VEX competitions.

The following chapters uncover the Engineering Design Process and the module itself. The literature review in chapter 2 reviews the importance of the Engineering Design Process in STEM education and how it fosters STEM students' learning. Chapter 3 contains a step-by-step description of an Engineering Design Process module that teaches how to design, assemble, and test a fully working 3D-printed mechanical toy in Autodesk Inventor Pro 2014, based on the unique *Engineer Your World*'s multi-level Engineering Design Process ("Course," n.d.). A quantitative and qualitative research analysis and evaluation of the module are presented in chapter 4. Chapter 5 includes suggestions for future improvements to this module.

Chapter 2: Review of Literature

2.1 Engineering Design Process in STEM Education

The Texas Education Agency (TEA) requires teachers to teach the Texas Essential Knowledge and Skills (TEKS), a set of standards and objectives students must master, rather than using the Common Core that has been adopted in forty-five states and the District of Colombia (Golod, 2014). As Texas is unique when it comes to education compared to the rest of United States, so is the way STEM education is regulated by the TEKS.

In Texas, the Engineering Design Process (EDP) is a focus of the Engineering Design and Problem Solving course, which provides one science credit if it is implemented in the 11th or 12th grade (Texas Education Agency, 2010). See Appendix A for more information about the Engineering Design Process and Problem Solving TEKS.

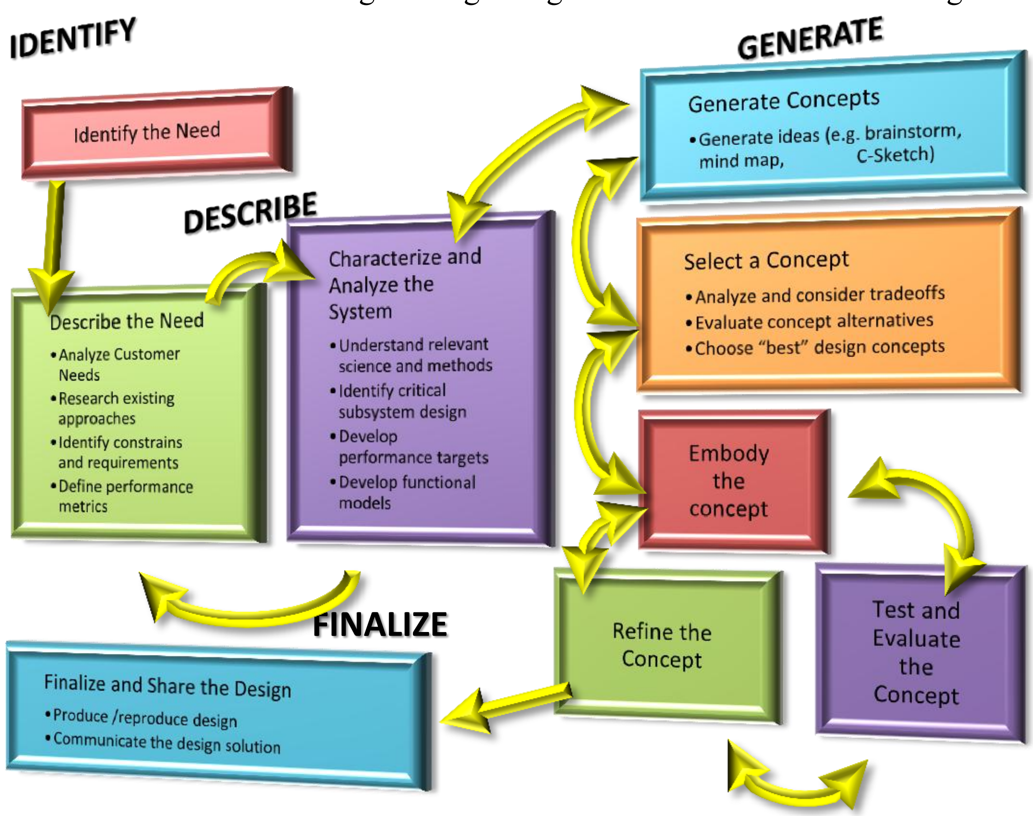

Figure 1. Engineer Your World's Engineering Design Standard Process ("Course," n.d.)

According to https://www.teachengineering.org/engrdesignprocess.php, a curriculum for K-12 funded by the National Science Foundation, the Engineering Design Process "is a series of steps that engineering teams use to guide them as they solve problems" (Engineering, n.d.). The process is "cyclical" as we can observe in Figure 1; there are arrows indicating that the steps can be repeated in order to make needed iterations, or improvements, before finishing with the final product. Important factors like teamwork and design play key roles in the Engineering Design Process. The Engineering Design Process "encourage[s] students to follow the steps of the design process to strengthen their understanding of open-ended design [with multiple solutions] and emphasize creativity and practicality" (Engineering, n.d.). The Engineering Design Process is also a fundamental topic in the Master of Arts in STEM in Education-Engineering (MASEE) Program at the University of Texas at Austin. Engineering design is covered in the fundamentals of engineering course, *Engineering Design Methods,* taught by Dr. David Allen and Dr. Richard Crawford, and in the *Design of Machines and Systems* taught by Dr. Crawford (Allen, Crawford, personal communication).

The *Engineering Design Methods* course introduces "students to the scope of engineering science, and engineering design…methods are addressed through rigorous design challenges and reverse engineering design modules [from creating simple toys with straws and rubber bands (see Figure 2) to making a fully working product prototypes]" (Allen, 2013). Similarly, Olin College offers a freshman introductory mechanical design and prototyping course, *Design Nature*, which introduces STEM and the EDP to students via an engineering challenge of creating a mechanical toy and helping them discover the underlying mathematics, physics and science principles. Students are challenged to design a nature-inspired toy prototype of a hopping, swimming, or climbing insect, and after completing the challenge they must design, prototype, and test a mechanical toy for fourth graders (Design, 2016). *Design Nature* focuses on introducing engineering right away before all prerequisite science and mathematics core courses with a hands-on experience that keeps students engaged and

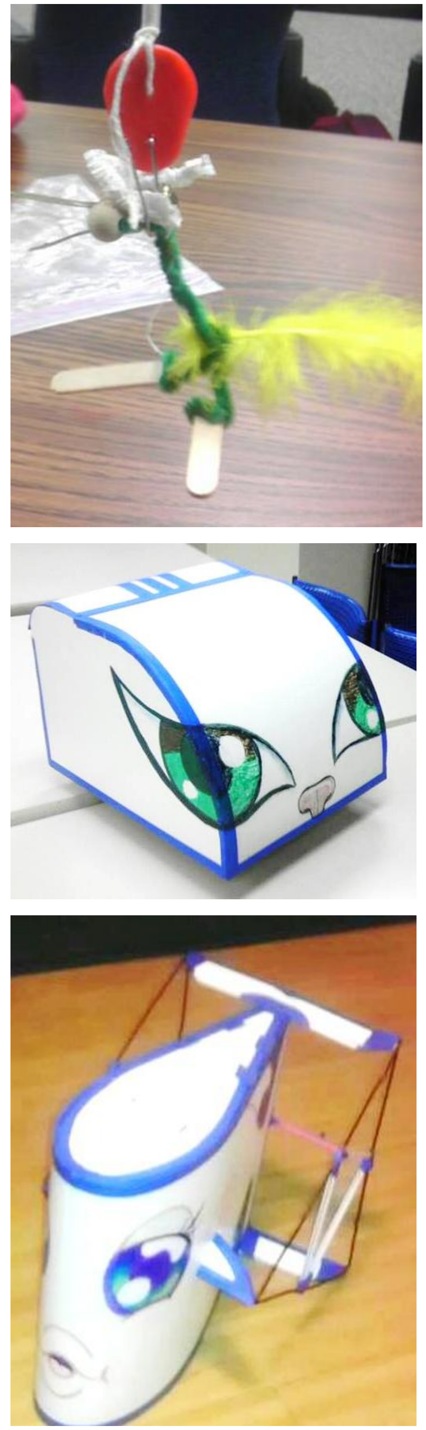

Figure 2. First toys created in June 2013 for the MASEE Program's Engineering Design Methods course.

interested in STEM. It can be concluded that both colleges, the University of Texas at Austin and Olin College, base their curricula on constructivism.

In the 1970 study, Jean Piaget hypothesized that children learn through interaction with their environments (Gash, 2014). This study is linked to todays' constructivism, where learners are exposed to challenges that help them discover and create their own answers (Gash, 2014). Two characteristics of constructivist thinking are "the circular nature of thinking [which occurs by repetition, or trial and error until the objective or solution is mastered and] …a recognition of the limits on what is known [in other words, knowing the constraints] (303)". According to Gash (2014), teachers become "guides and mentors rather than instructors" (306). Teachers themselves learn as students learn and discover solutions. Because there is no definitive answer or solution, teachers should teach students that it is alright to be wrong, and to work with uncertainty in order to emerge in their thinking and find many solutions (Gash, 2014).

Examples of constructivist tools are the programming languages Logo and Scratch. As a constructivist tool to teach mathematics, Logo was largely used in the 1970's "…to involve users in computer programming...[and] as an aid to enhancing learning in areas…at all levels from kindergarten to university (75)." The intent for Logo was to teach mathematics through programming. Similarly to Logo, Scratch, a Web 2.0 programing language that was easy to use, was introduced in the classroom in non-IT subjects (Jones, 2015). As programming software is used as a tool to teach different subjects in the constructivist creation of video games, CAD software like Autodesk

Inventor targets STEM education, allowing the user to design different prototypes or solutions and test them.

Like the introductory courses at Olin College and the University of Texas at Austin, the Engineering Design Process module, ROBO-TITO, described in this report, is designed to capture students' attention while teaching concepts of STEM. It uses constructivist pedagogy, where the student is challenged to create a fully working 3D-printed mechanical toy using the EDP.

Because of its wide applicability to solving problems and challenges in the engineering field, the EDP can easily be leveraged to other subjects in science, technology, engineering and mathematics by varying the nature of the engineering design challenge and its complexity. Therefore, the EDP is a perfect tool for STEM education.

Engineering design challenges can help teachers address all of the Engineering Habits of Mind to "demonstrate complete and enduring modeling of systems thinking, creativity, optimism, collaboration, communication, and attention to ethics…(17)". These habits are part of the 21st Century framework, Standards for Technological Literacy and Advancing Excellence in Technology Literacy, and Next Generation Science Standards. Engineering Design embodies *engineering habits of mind*, "an essential skill to separate how engineers think and act from the ways that academic content teachers think and act (13)." (Loveland, 2014). Examples of existing programs and curricula that use *engineering habits of mind,* which have in common the practice of the EDP, include *Engineer Your World* and FIRST. *Engineer Your World*, developed by the UTeach*Engineering* Program of the University of Texas at Austin, is an innovative high school engineering curriculum that focuses on real world design challenges that use *engineering habits of mind* so students develop and practice engineering skills (Course Description, n.d.). Also, FIRST uses *engineering habits of mind* through Gracious Professionalism®, part of the "ethos of FIRST". The term was coined by Dr. Woodie Flowers, FIRST Distinguished Advisor and Pappalardo Professor Emeritus of Mechanical Engineering, Massachusetts Institute of Technology. The term means to be effective and professional when working, while respecting others, both individuals and the community. FIRST also espouses Coopertition®, which, according to FIRST, produces innovation due to the fact that teams learn from each other while they help and collaborate with each other during competition.

Katehi et al. (2009) assert that just "developing a curriculum does not guarantee that engineering education in K-12 will be successful" (71). The authors recommend that teachers must understand basic engineering concepts, have a background in STEM, or collaborate with teachers that have a background in science or mathematics. Teachers also need to be comfortable in engaging and teaching engineering design (Katehi, 2009). Clearly the Engineering Design Process is very important in engineering education. Not only must students learn the EDP, but teachers themselves must be able to teach it effectively. Engineering education in K-12 must include training for teachers in engineering design. The American Society for Engineering Education (ASEE) K-12 Leadership Workshop provides six guidelines to improve K-12 engineering education (Douglas, 2004):

1. *Use/Improve K-12 Teachers* by making teachers better, or by hiring teachers with knowledge in STEM.
2. Provide *hands-on learning* by using the do-it strategy.
3. Take an *interdisciplinary approach* by mixing writing with mathematics and science, and adding technology to all courses.
4. Adhere to *standards* by using engineering lessons that involve mathematics and science standards.
5. *Make Engineers "Cool"* by inviting mentors and engineers to school.
6. Develop *partnerships* by creating incentives for organizations to be engaged in the education and in the community.

Engineering education involves all aspects of STEM, and using these suggested guidelines to prepare teachers for this discipline can make engineering education in K-12 successful. Furthermore, it is very important that teachers teach and understand the STEM education framework, and use best engineering practices like the Engineering Design Process and project-based instruction through relevant STEM challenges that motivate and inspire all students.

2.2 How the Engineering Design Process Fosters STEM Students' Learning

How many times have we heard the term do-it-yourself (DIY)? One distinguishing characteristic of the Engineering Design Process is that it is best by taught by solving challenges and "doing" it, or as it is called in the education field, *hands-on activities.* Doing plays a key role in STEM education and learning overall. As Confucius, a Chinese philosopher and teacher, declares: "I hear and I forget. I see and I remember. I do and I understand". Moyee et al. (2014) have shown that middle and high school technology and engineering students learn more concepts by "doing" than students in science and mathematics classrooms (27). Students in technology and engineering courses are exposed to laws, principles, theories, strategies, designs, and processes from science, technology, engineering and mathematics, and they are provided with contexts in which these concepts are applied. This is in contrast to students in traditional education settings, where students and teachers experience "teaching to the test" (Moyee 24). Using the Engineering Design Process as part of STEM education can help students master content through doing-based activities and finding solutions to specific challenges. For example, in real-world product manufacture, the assembly process, which consists of combining parts in an assembly to make a product, is an important step in production. This process takes place during the finalize stages of the Engineering Design Process; students can easily benefit from solving not only the design challenge in order to create a product, but from thinking about ways to speed up production. They can "develop a product design that ensures correct, flawless, and fast and inexpensive as possible installation" (Sąsiadek 337). Strategies like the Activity Diagram, a technique used in *Engineer Your World* to understand how a customer uses a product, can help students design and think about producing a product with characteristics that will not only benefit the end user, but help speed up the production process as well. To learn about these techniques, students have to "do it" and solve the problem themselves. Therefore, the Engineering Design Process is a perfect framework for teaching through "doing".

2.3 SUMMARY

The Engineering Design Process contains skills and processes needed for STEM education and can easily be integrated in the *Engineering Design and Problem Solving Curriculum*. It is the framework that engineers engage in on a daily basis. Engineers create instructions on how products are to be designed, tested, and assembled. They design solutions to a problem taking into consideration scarce resources and know "how physical objects behave while in motion (Katehi 28)".

STEM teachers can be more effective by implementing engineering design techniques and methods in the classroom. Hands-on, do-it activities, critical thinking, brainstorming, collaboration and problem solving all are part of the Engineering Design Process. Therefore the Engineering Design Process merits consideration in STEM education.

Chapter 3: Engineering Design Process Module: *ROBO-TITO*

The Engineering Design Process Module, *ROBO-TITO*, named in memory of my pet parrot, was inspired by the course *Design of Machines and Systems* (Summer 2014) taught by Dr. Richard H. Crawford as part of the UTeach*Engineering* Master of Arts in STEM Education – Engineering (MASEE) at the University of Texas at Austin. *Design of Machines and Systems* is a course for teachers of secondary-grade engineering that focuses on engineering methods and mechanical component design. I specifically extracted the standardized *Engineer Your World Engineering Design Process* to create this interactive module to be used as a learning tool for students and teachers interested in engineering.

The module was created using software available at no cost for educational purposes, and open source software (also called freeware). The software and languages used to create *ROBO-TITO* include the following:

- Autodesk Inventor Professional
- Autodesk Screencast
- Wix.com
- HTML
- Microsoft Office Power Point
- GIMP
- InkScape
- Bubbl.us
- MakerBot Desktop

3.1 Product Description: About the Engineering Design Process Module

ROBO-TITO targets young students interested in obtaining new professional skills, and/or practicing their current Engineering Design Process skills. Teachers have access to a student-centered Engineering Design Process module that can be implemented in different ways. This is a hands-on module, which uses a “do-it-yourself” strategy and “think out loud” teaching methods. According to Moyee (2014), “Middle and high school technology and engineering students are learning by doing more than are students in science and mathematics classrooms.”

ROBO-TITO is designed to keep students engaged in a 100% hands-on, real world activity, and facilitates the process of teaching the EDP for teachers. Teachers can also choose to form groups of students and turn the module into a challenge or friendly competition among teams, in order to solve the challenge faster by using a jigsaw strategy. Using this approach, each student designs a part individually and then prints it out individually. The team members then figure out how to assemble the whole system as a puzzle. Once done, other students from another class can perform reverse engineering to figure out how it works.

As stated above, the product is an Engineering Design Process module that students in grades 9-12 and their teachers can use to learn and or teach the Engineering Design Process. Even though it shares very similar characteristics to an *Engineer Your World* Challenge, it is not based on any of the Grand Challenges of Engineering. It is a project that is feasible for students to complete in groups or individually at their own pace.

The module includes the following components (see Figures 3-18 for screen shots of module pages):

- PDF manual on how to navigate and use the module for students and teachers
- Teacher notes, rubrics, and visible TEKS in every section of the Engineering Design Process

- Easy and accessible interactive vocabulary words, buttons, links and embedded videos (YouTube, Autodesk Screencast, and other streaming media videos)
- Step-by-step instructions on how to design, build, test and 3D print a fully working mechanical toy through interactive screencasts
- All files, assemblies, and parts of the mechanical toy "*ROBO-TITO*" for Autodesk Inventor 2014 and MakerBot Replicator .stl files can be e-mailed upon request at no cost.

Student-Paced	Teacher-Paced
Depending on student capabilities, they might choose different Engineering Design Process sections, or jump right to the prototype section. They can always design their own product using the same techniques shown in *ROBO-TITO* and have the module open as a reference when working with the Engineering Design Process, or when using Autodesk Inventor.	Teachers choose what part to model, or what concept to teach. Ask students to form teams and work on modeling and printing each part. Teachers can create entire lessons from different sections of the module. *Tables 2, 3, 4 and 5 show how the module can be integrated in a lesson and illustrate activities students can work on as a class.*

Table 1: Two ways to use the Engineering Design Process module, *ROBO-TITO*

3.2 TEKS and Objectives

The Texas Essential Knowledge and Skills are the objectives that the Texas Education Agency sets for a particular course. The Engineering Design Process Module, *ROBO-TITO*, is aligned with chapter §130.373, Engineering Design and Problem Solving. Only some of the TEKS are included within the module, but all of the Engineering Design and Problem Solving TEKS could be implemented if the teacher decides to expand the module and assign side projects for presentations, or specific tasks and activities during class. Turn to Appendix A to see the Engineering Design and Problem Solving TEKS.

3.3 *ROBO-TITO* Module

As an example, this section illustrates one possible use of the *ROBO-TITO* module. The table below shows how *ROBO-TITO* can be implemented during the second semester of the Engineering Design and Problem Solving course. It includes a lesson schedule for 90 days with the list of the TEKS, The Learner Will (TLW – activities and results the student will produce), the name of each section of the module, and a reference to a figure showing the relevant web page(s). The figures follow the table.

1st 6 Weeks	Major Assessment	Progress Report	Report Card	Semester Exam
Monday	Tuesday	Wednesday	Thursday	Friday
1	2	3	4	5
TEKS: 4: d-f Introduction/Quick Write Activity TLW: Answer the following question in a quick write: What is the Engineering Design Process and how does it work?	TEKS: b) 1-2 TLW: Take Cornell Notes from lecture in their Engineering Notebook Engineering Design Process-Lecture (See Figure 4)	TEKS: b) 3 TLW: Take Cornell Notes (CN) from lecture in their Engineering Notebook Engineering Design Process-Lecture (See Figure 4)	TEKS: 6: c TLW: Make groups of no more than four based on class size and abilities	Instructions, Expectations and Rubric for *ROBO-TITO*. TLW: Write Cornell Notes during the entire module in their Engineering Notebooks. (See Figure 3)
6	7	8	9	10
TEKS: 3: a, 6: i TLW: Draw the EDP, label it and color each section without looking at the module. After completion, the student will write a description on each section of the EDP. (See Figure 4)	TEKS: 5: a TLW: Listen and write CNs from the information presented. Identify the Need (See Figure 5)	TEKS: 3: e; 5: c, d TLW: Create an Affinity Analysis table and interview other students to analyze the customer needs. Describe the Need: Analyze Customer Needs (See Figure 6)	TEKS: 5: e TLW: Search for similar products online, and/or perform a reverse engineering in case of an existing mechanical toy. Describe the Need: Research Existing Approaches (See Figure 7)	TEKS: 5: b; 6: f TLW: Look at what is available in the classroom as for to create the toy. Describe the Need: Identify constraints and requirements (See Figure 7)

Table 2: Lesson Schedule for the Engineering Design Process module, *ROBO-TITO*

11	12	13	14	15
TEKS: 5: c TLW: Create a Needs-Metric Table in their Engineering Notebooks. Describe the Need: Define performance metrics (See Figure 7)	TEKS: 2: a, b, d, e, g TLW: Take CNs from what is provided in the module and research online for more formulas. Characterize the System: Understand relevant science and methods (See Figure 8)	TEKS: 2: a, f, g TLW: Create a Black Box in their Engineering Notebook Characterize and Analyze the System: Identify critical subsystem design (See Figure 8)	TEKS: 5 d TLW: Use the performance metrics table and indicate what you as a group are going to target Characterizer and Analyze the System: Develop performance targets (See Figure 8)	TEKS: 5: c, h TLW: Create an Activity Diagram and a Functional Tree Model on their Engineering Notebook. Characterize and Analyze the System: Develop functional models (See Figure 8)
16	17	18	19	20
TEKS: 5: e; 3: a, b, c, d, e, & f TLW: Brainstorm with their team members and then create a Mind Map using bubbl.us Generate Concepts: Generate ideas (i. e. brainstorm, mind map, C-Sketch) (See Figure 9)	TEKS: 5: e; 3: a, b, c, d, e, & f TLW: Create a C-Sketch with their team Generate Concepts: C-Sketch (See Figure 10)	TEKS: 5: g TLW: Select a Concept: Analyze and consider tradeoffs (See Figure 11)	TEKS: 5: g-h TLW Create a Pugh chart form their C-Sketches Select a Concept: Evaluate concept alternatives (See Figure 11)	TEKS: 5:i TLW: Evaluate and choose a design to make using the Pugh Chart Select a Concept: Choose the best Design (See Figure 11)
21	22	23	24	25
TEKS: 3-5 TLW: Take a written evaluation to explore key concepts and to check their understanding and mastery of the objectives. Assessment on concepts covered from day 1-20	TEKS: 6: a, b, c, d, e TLW: Choose and split tasks among team members Embody the Concept: Split parts among team members (See Figure 12)	TEKS: 2: f-k, 6: a TLW: Use the module to learn how to make 3D parts in Autodesk Inventor Embody Concept: Model Gears (See Figure 13)	TEKS: 2: f-k, 6: a TLW: Create gears in the CAD Software Embody Concept: Model Gears (See Figure 14)	TEKS: 2: f-k, 6: a TLW: Create gears in the CAD Software Embody Concept: Model Gears (See Figure 14)
26	27	28	29	30
TEKS: 2: f-k, 6: a TLW: Create gears in the CAD Software Embody Concept: Model Gears (See Figure 14)	TEKS: 2: f-k, 6: a TLW: Create gears in the CAD Software Embody Concept: Model Gears (See Figure 14)	TEKS: 2: f-k, 6: a TLW: Create gears in the CAD Software Embody Concept: Model Gears (See Figure 14)	TEKS: 2: f-k, 6: a TLW: Create gears in the CAD Software Embody Concept: Model Gears (See Figure 14)	TEKS: 2: f-k, 6: a TLW: Create gears in the CAD Software Embody Concept: Model Gears (See Figure 14)
2nd 6 Weeks				
31	32	33	34	35
TEKS: 2: f-k, 6: a TLW: Model part in the CAD Software Embody Concept: Model Feet (See Figure 14)	TEKS: 2: f-k, 6: a TLW: Model part in the CAD Software Embody Concept: Model Feet (See Figure 14)	TEKS: 2: f-k, 6: a TLW: Model part in the CAD Software Embody Concept: Model Feet (See Figure 14)	TEKS: 2: f-k, 6: a TLW: Model part in the CAD Software Embody Concept: Model Feet (See Figure 14)	TEKS: 2: f-k, 6: a Model part in the CAD Software Embody Concept: Model Feet (See Figure 14)
36	37	38	39	40
TEKS: 2: f-k, 6: a TLW: Model part in the CAD Software Embody Concept: Model Body (See Figure 14)	TEKS: 2: f-k, 6: a TLW: Model part in the CAD Software Embody Concept: Model Body (See Figure 14)	TEKS: 2: f-k, 6: a TLW: Model part in the CAD Software Embody Concept: Model Body (See Figure 14)	TEKS: 2: f-k, 6: a TLW: Model part in the CAD Software Embody Concept: Model Body (See Figure 14)	TEKS: 2: f-k, 6: a Model part in the CAD Software Embody Concept: Model Body (See Figure 14)

Table 2, Cont.

41	42	43	44	45
TEKS: 2: f-k, 6: a TLW: Model part in the CAD Software Embody Concept: Model Head (See Figure 14)	TEKS: 2: f-k, 6: a TLW: Model part in the CAD Software Embody Concept: Model Head (See Figure 14)	TEKS: 2: f-k, 6: a TLW: Model part in the CAD Software Embody Concept: Model Head (See Figure 14)	TEKS: 2: f-k, 6: a TLW: Model part in the CAD Software Embody Concept: Model Head (See Figure 14)	TEKS: 2: f-k, 6: a TLW: Model part in the CAD Software Embody Concept: Model Head (See Figure 14)
46	47	48	49	50
TEKS: 2: f-k, 6: a TLW: Model part in the CAD Software/Assemble parts Embody the Concept: Assemble (See Figure 15)	TEKS: 2: f-k, 6: a TLW: Model part in the CAD Software/Assemble parts Embody the Concept: Assemble (See Figure 15)	TEKS: 2: f-k, 6: a TLW: Model part in the CAD Software/Assemble parts Embody the Concept: Assemble (See Figure 15)	TEKS: 2: f-k, 6: a TLW: Model part in the CAD Software/Assemble parts Embody the Concept: Assemble (See Figure 15)	TEKS: 2: f-k, 6: a TLW: Model part in the CAD Software/Assemble parts Embody the Concept: Assemble (See Figure 15)
51	52	53	54	55
TEKS: 2: f-k, 6: a TLW: Model part in the CAD Software/Assemble parts Embody the Concept: Assemble (See Figure 15)	TEKS: 2: f-k, 6: a TLW: Model part in the CAD Software/Assemble parts Embody the Concept: Assemble (See Figure 15)	TEKS: 2: f, j TLW: Use advanced features in CAD to analyze and test design Test and Evaluate: Check Constraints and Play Assembly (See Figure 15)	TEKS: 2: f, j TLW: Use advanced features in CAD to analyze and test design Test and Evaluate: Check Constraints and Play Assembly (See Figure 15)	TEKS: 2: f, j TLW: Use advanced features in CAD to analyze and test design Test and Evaluate: Check Constraints and Play Assembly (See Figure 15)
56	57	58	59	60
TEKS: 2: e TLW: Use advanced features in CAD to analyze and test design Refine the Concept: Make changes in assembly mode (See Figure 16)	TEKS: 2: e TLW: Use advanced features in CAD to analyze and test design Refine the Concept: Make changes in assembly mode (See Figure 16)	TEKS: 2: e TLW: Use advanced features in CAD to analyze and test design Refine the Concept: Make changes in assembly mode (See Figure 16)	TEKS: 2: f, j TLW: Use advanced features in CAD to analyze and test design Test and Evaluate: Check Constraints and Play Assembly (See Figure 15)	TEKS: 2: e TLW: Use advanced features in CAD to analyze and test design. Re-design if needed. Refine the Concept: Make changes in assembly mode (See Figure 16)
3rd 6 Weeks				
61	62	63	64	65
TEKS: 1: b; 2: k; 6: e TLW: Use 3D Printer, and supervise to set it up and to clear jams Finalize and Share Design: Produce and Reproduce-->3D Print (See Figure 17)	TEKS: 1: b; 2: k; 6: e TLW: Use 3D Printer, and supervise to set it up and to clear jams Finalize and Share Design: Produce and Reproduce-->3D Print (See Figure 17)	TEKS: 1: b; 2: k; 6: e Finalize and Share Design: Produce and Reproduce-->3D Print (See Figure 17)	TEKS: 1: b; 2: k; 6: e Finalize and Share Design: Produce and Reproduce-->3D Print (See Figure 17)	TEKS: 1: b; 2: k; 6: e Finalize and Share Design: Produce and Reproduce-->3D Print (See Figure 17)
66	67	68	69	70
TEKS: 1: b; 2: k; 6: e TLW: Use 3D Printer, and supervise to set it up and to clear jams Finalize and Share Design: Produce and Reproduce-->3D Print (See Figure 17)	TEKS: 1: b; 2: k; 6: e TLW: Use 3D Printer, and supervise to set it up and to clear jams Finalize and Share Design: Produce and Reproduce-->3D Print (See Figure 17)	TEKS: 1: b; 2: k; 6: e TLW: Use 3D Printer, and supervise to set it up and to clear jams Finalize and Share Design: Produce and Reproduce-->3D Print (See Figure 17)	TEKS: 1: b; 2: k; 6: e TLW: Use 3D Printer, and supervise to set it up and to clear jams Finalize and Share Design: Produce and Reproduce-->3D Print (See Figure 17)	TEKS: 1: b; 2: k; 6: e TLW: Use 3D Printer, and supervise to set it up and to clear jams Finalize and Share Design: Produce and Reproduce-->3D Print (See Figure 17)

Table 2, Cont.

71	72	73	74	75
TEKS: 1: b; 2: k; 6: e TLW: Use 3D Printer, and supervise to set it up and to clear jams Finalize and Share Design: Produce and Reproduce-->3D Print (See Figure 17)	TEKS: 1: b; 2: k; 6: e TLW: Use 3D Printer, and supervise to set it up and to clear jams Finalize and Share Design: Produce and Reproduce-->3D Print (See Figure 17)	TEKS: 1: b; 2: k; 6: e TLW: Use 3D Printer, and supervise to set it up and to clear jams Finalize and Share Design: Produce and Reproduce-->3D Print (See Figure 17)	TEKS: 1: b; 2: k; 6: e TLW: Use 3D Printer, and supervise to set it up and to clear jams. /Show all parts completed Finalize and Share Design: Produce and Reproduce-->3D Print (See Figure 17)	TEKS: 1: b; 2: k; 6: e TLW: Use 3D Printer, and supervise to set it up and to clear jams Finalize and Share Design: Produce and Reproduce-->3D Print (See Figure 17)
76	77	78	79	80
TEKS: 2: d; 6: g TLW: Refine the Concept: Sand it and fix each part for assembly (See Figure 18)	TEKS: 2: d; 6: g TLW: Refine the Concept: Sand it and fix each part for assembly (See Figure 18)	TEKS: 2: d; 6: g TLW: Refine the Concept: Sand it and fix each part for assembly (See Figure 18)	TEKS: 2: d; 6: g TLW: Refine the Concept: Sand it and fix each part for assembly (See Figure 18)	TEKS: 2: d; 6: g TLW: Refine the Concept: Sand it and fix each part for assembly (See Figure 18)
81	82	83	84	85
TEKS: 2: a, b TLW: Assemble the toy and make it work Finalize and Share Design: Assemble (See Figure 18)	TEKS: 2: a, b TLW: Assemble the toy and make it work Finalize and Share Design: Assemble (See Figure 18)	TEKS: 2: a, b TLW: Assemble r the toy and make it work Finalize and Share Design: Assemble (See Figure 18)	TEKS: 2: a, b TLW: Assemble the toy and make it work Finalize and Share Design: Assemble (See Figure 18)	TEKS: 2: a, b TLW: Assemble the toy and make it work Finalize and Share Design: Assemble (See Figure 18)
86	87	88	89	90
TEKS: 3: a-f; 6: h, i TLW: Give a presentation and show case their final product as a team Finalize and Share Design: Communicate the design solution-->Presentations (See Figure 18)	TEKS: 3: a-f; 6: h, i TLW: Give a presentation and show case their final product as a team Finalize and Share Design: Communicate the design solution-->Presentations (See Figure 18)	TEKS: 3: a-f; 6: h, i TLW: Give a presentation and show case their final product as a team Finalize and Share Design: Communicate the design solution-->Presentations (See Figure 18)	TEKS: 3: a-f; 6: h, i TLW: Give a presentation and show case their final product as a team Finalize and Share Design: Communicate the design solution-->Presentations (See Figure 18)	TEKS: 3: a-f; 6: h, i TLW: Give a presentation and show case their final product as a team Finalize and Share Design: Communicate the design solution-->Presentations (See Figure 18)

Table 2, Cont.

Figure 3. *ROBO-TITO's* Splash Page (http://carmen709.wix.com/robo-tito), contains a brief introduction to the module and all the links to navigate to the rest of the module. The splash page includes a link to the instructions for users that do not know how to use the module.

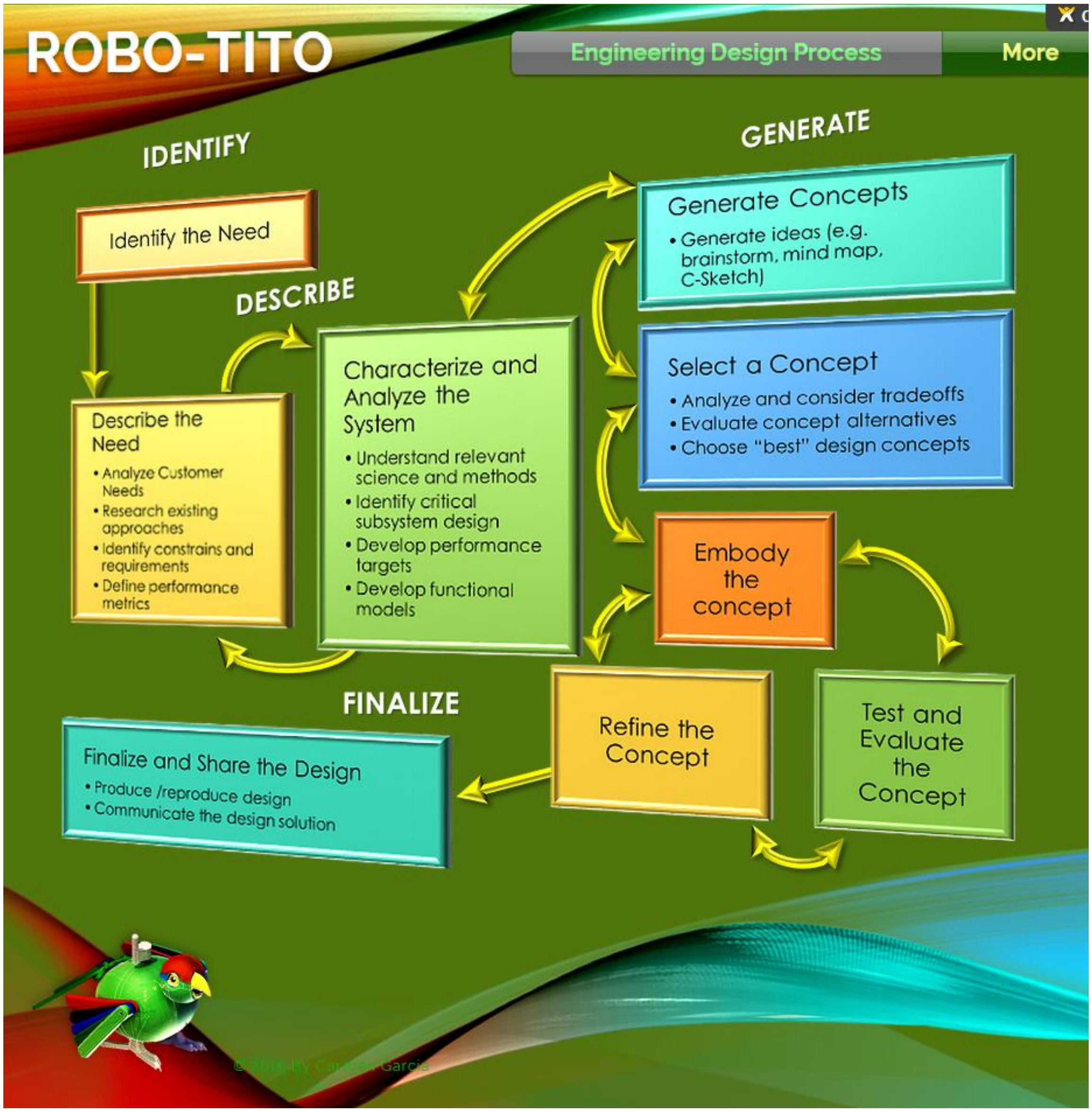

Figure 4. Engineer Your World's Engineering Design Standard Process from UTeach*Engineering* ("Course," n.d.); an interactive navigation page.

Figure 5. *ROBO-TITO's* identify page from the Engineering Design Process includes a catchy video to capture users' attention. It lets them explore and muse about possibilities in order to solve the given challenge.

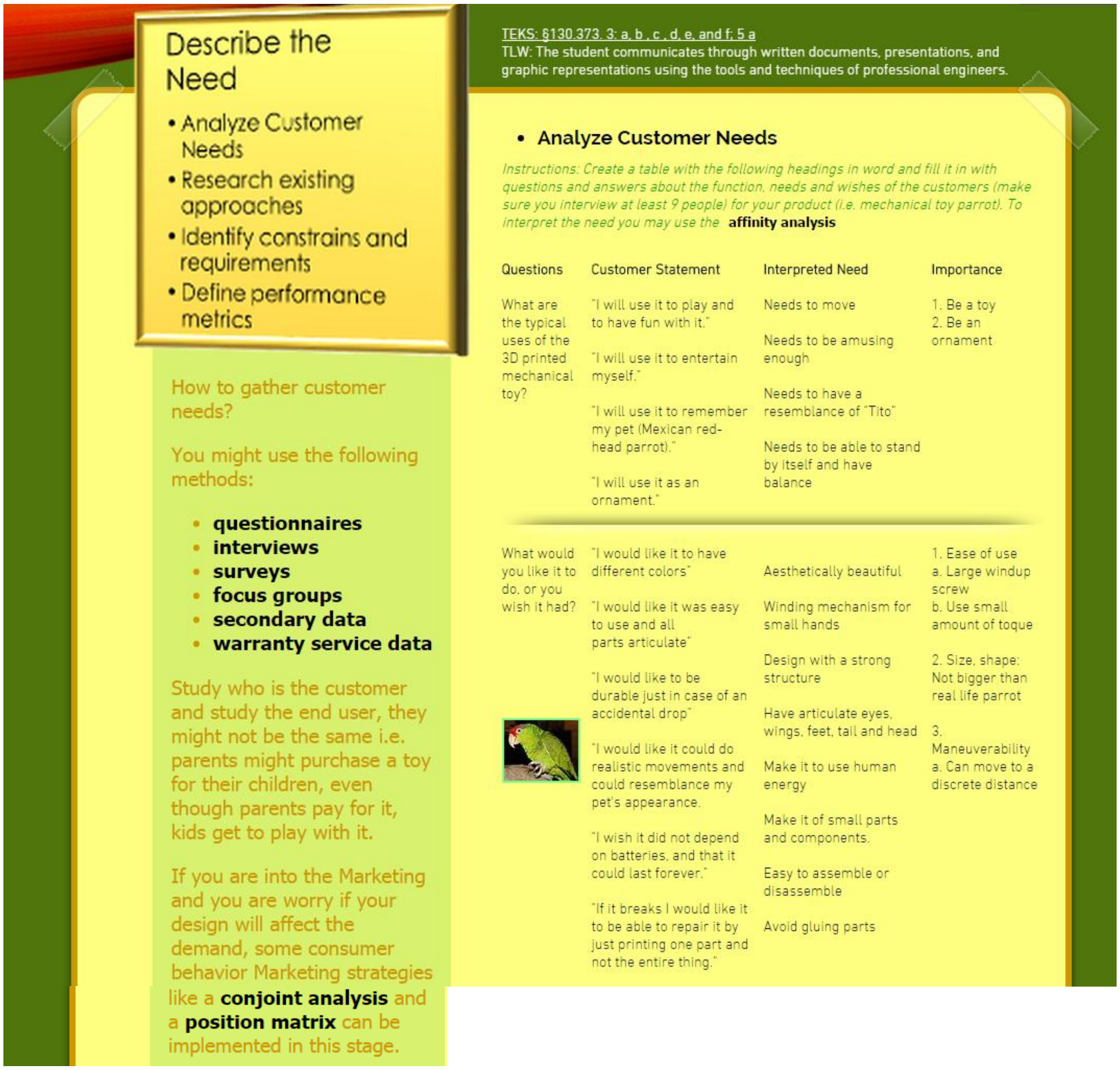

Figure 6. *ROBO-TITO's* describe page from the Engineering Design Process, *Describe the Need,* includes mouse-over definitions of key terms in bold and a sample of the affinity analysis table. It also includes research of existing approaches and videos for anything that looks like a 3D printed mechanical toy, and a list of constraints shown in page 24.

Figure 7. *ROBO-TITO*'s describe page from the Engineering Design Process, shows the *Needs-Metrics Table* sample, and some side information about different 3D printing materials that can be used for making the mechanical toy.

Figure 7, Cont.

Figure 8. *ROBO-TITO*'s describe page from the Engineering Design Process, *Characterize and Analyze the System*, includes relevant science concepts and methods, a list of different gears, mechanical parts, 3D terminology…

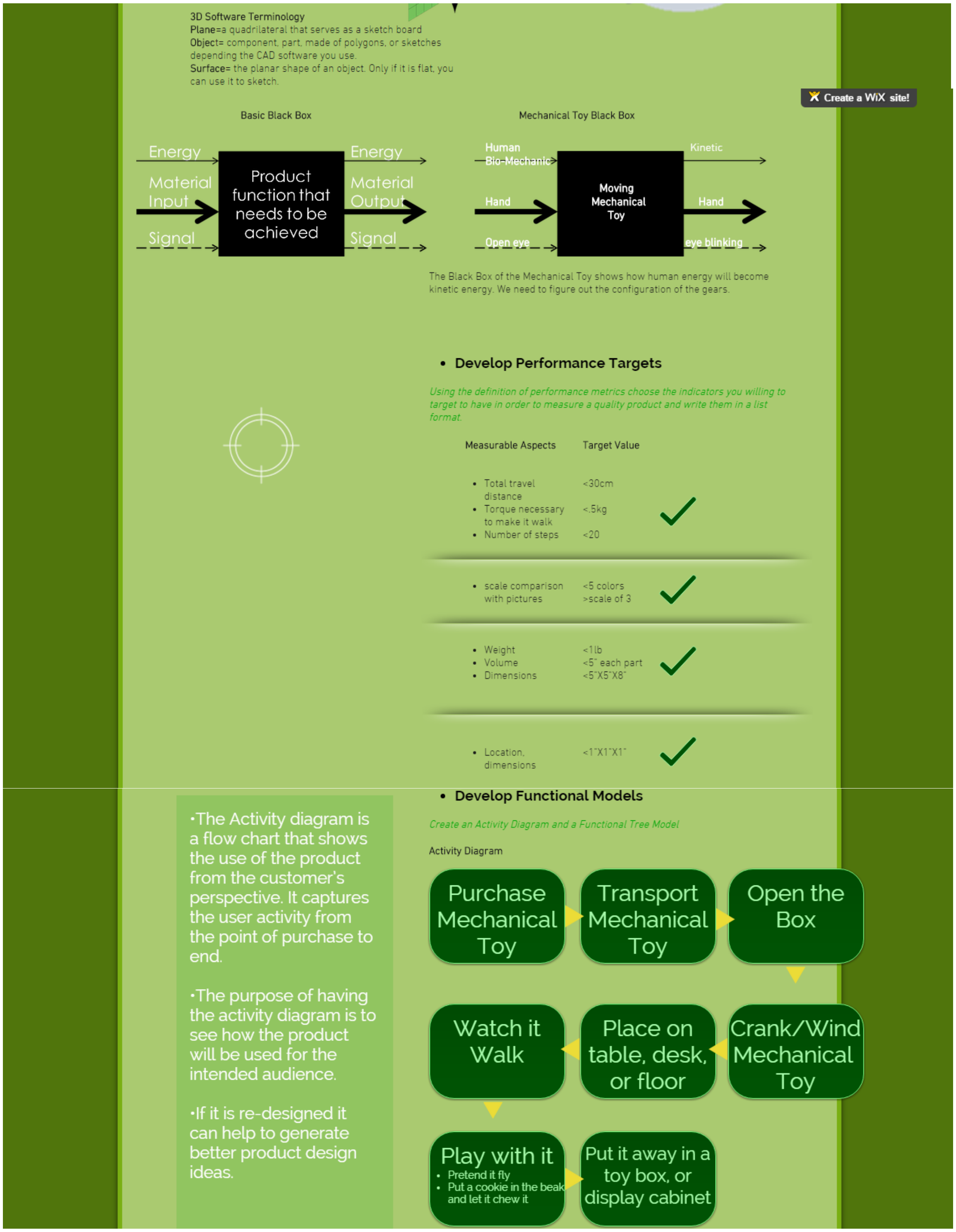

Figure 8, Cont.…sample black box, sample performance targets, an Activity Diagram, and …

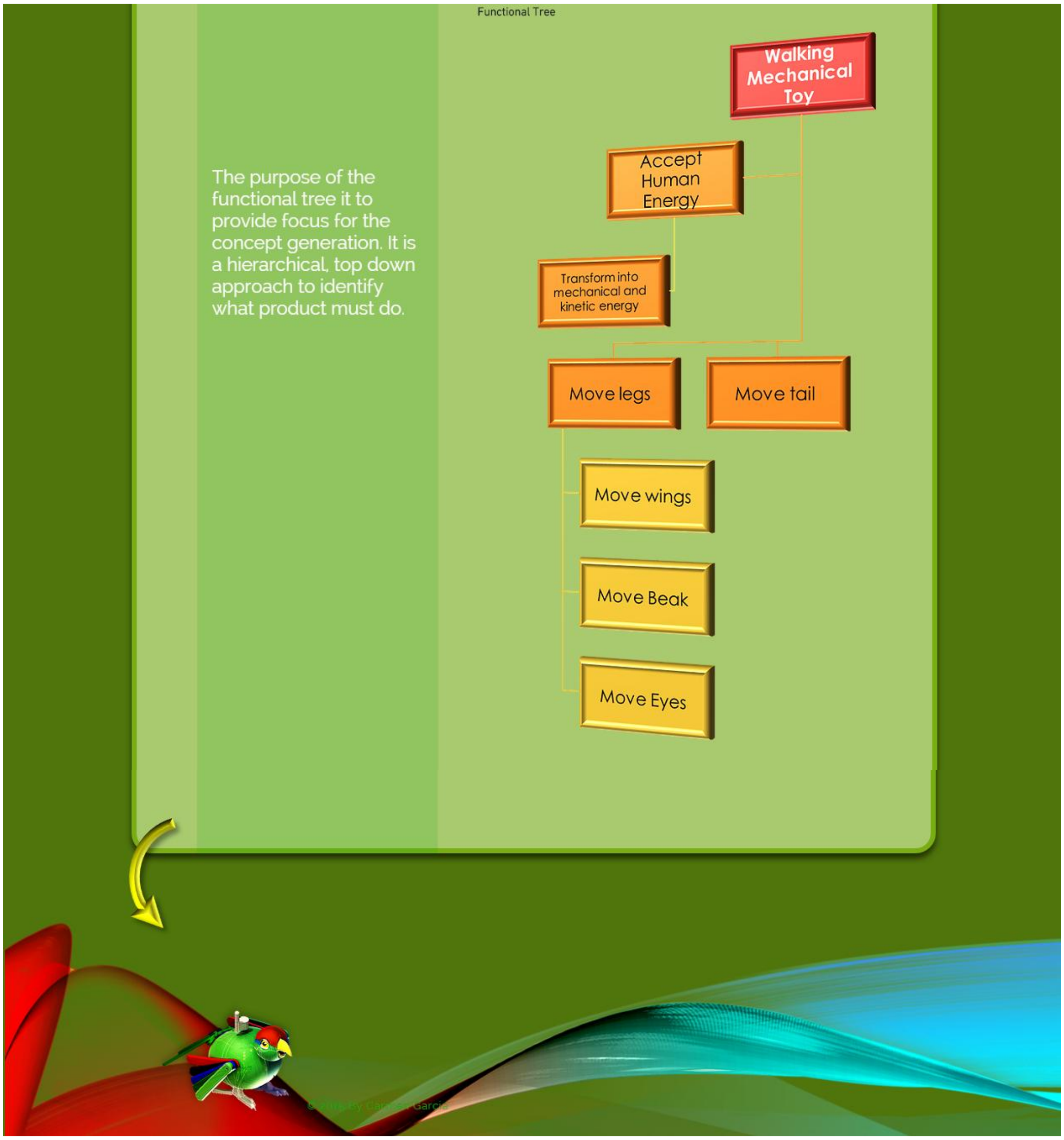

Figure 8, Cont.… a sample Functional Tree for the *ROBO-TITO* mechanical toy. Some images are links that can take the user to the original source, or to more samples.

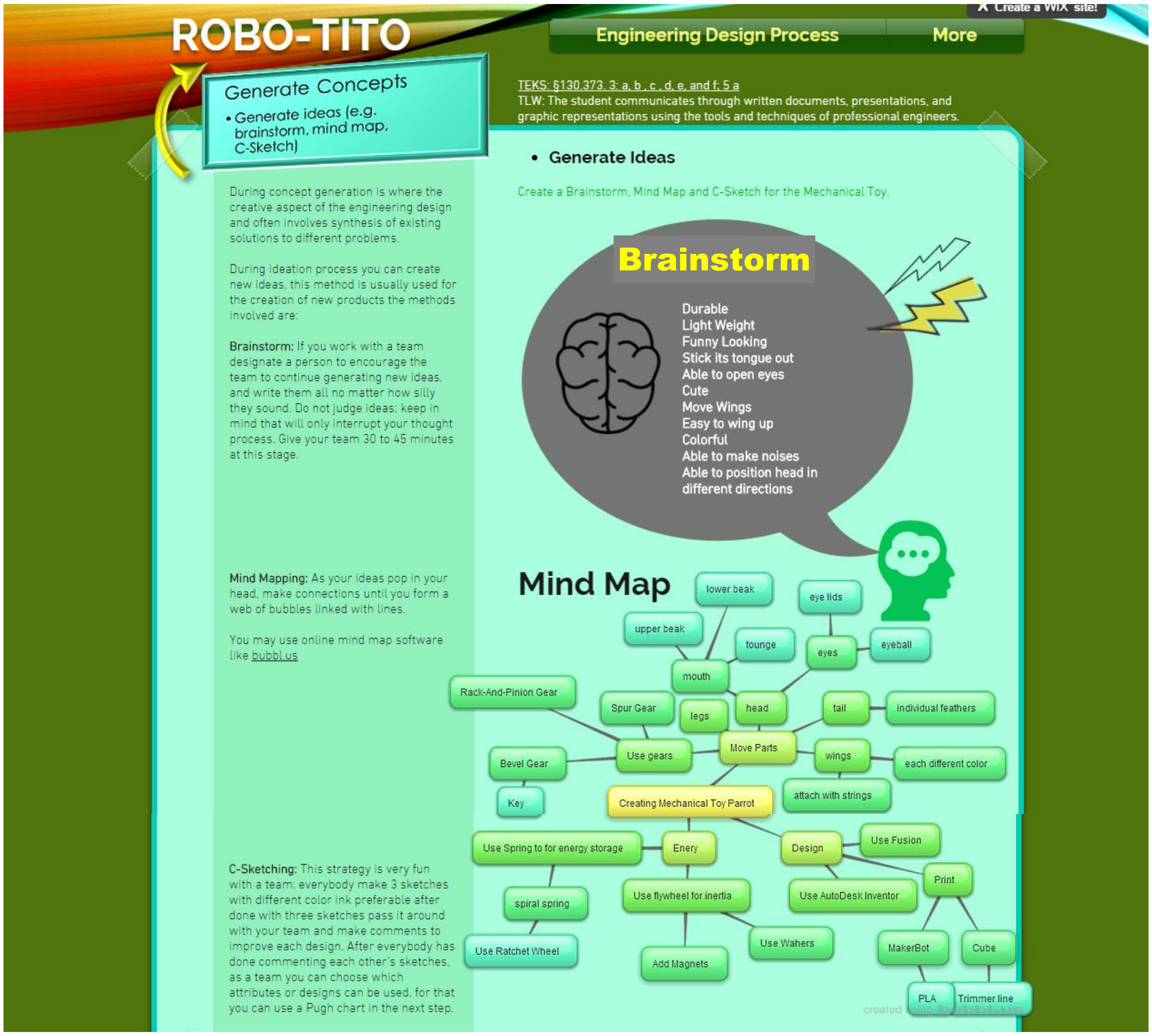

Figure 9. *ROBO-TITO*'s generate page from the Engineering Design Process, *Generate Ideas*, showing the Brainstorm sample and the Mind Map. The mind map in this page is a link that takes the user to bubbl.us so they can create their own mind map.

C-Sketch

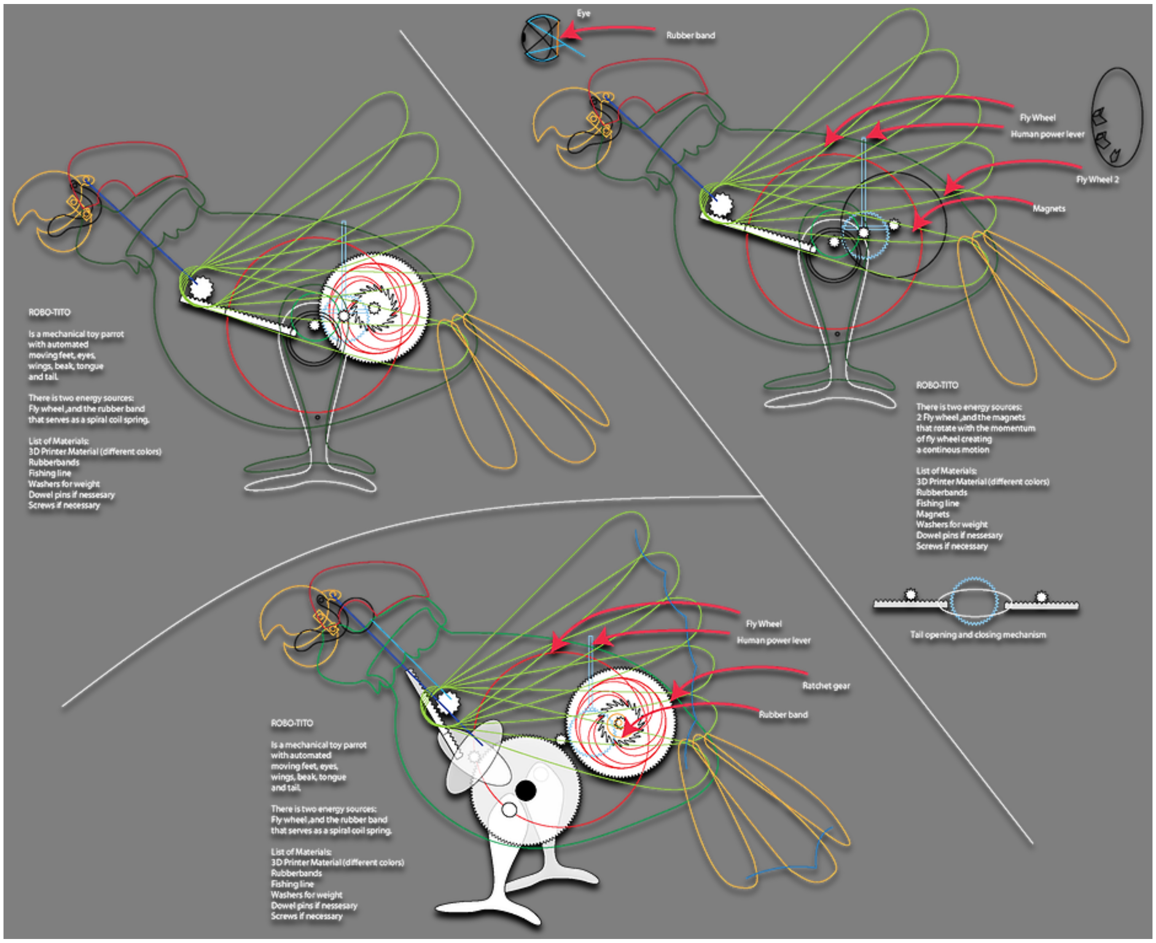

Figure 10. *ROBO-TITO*’s generate page from the Engineering Design Process, *Generate Ideas*, shows a sample C-Sketch with 3 different designs. Design and wording is in small print purposely, so users think about other possibilities that are not mentioned in the sample when creating their own C-sketches.

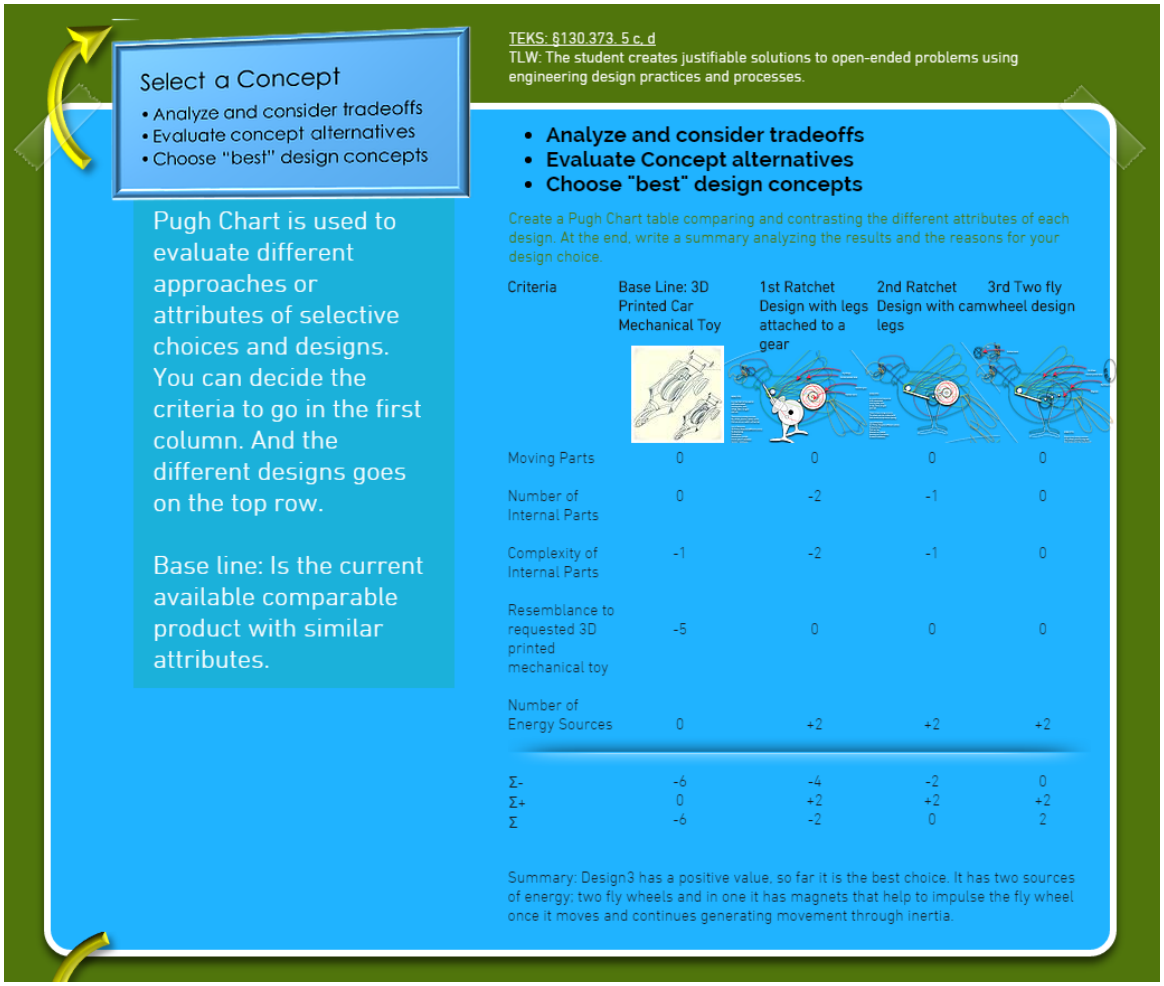

Figure 11. *ROBO-TITO*'s generate page from the Engineering Design Process, *Select a Concept,* shows a sample Pugh Chart.

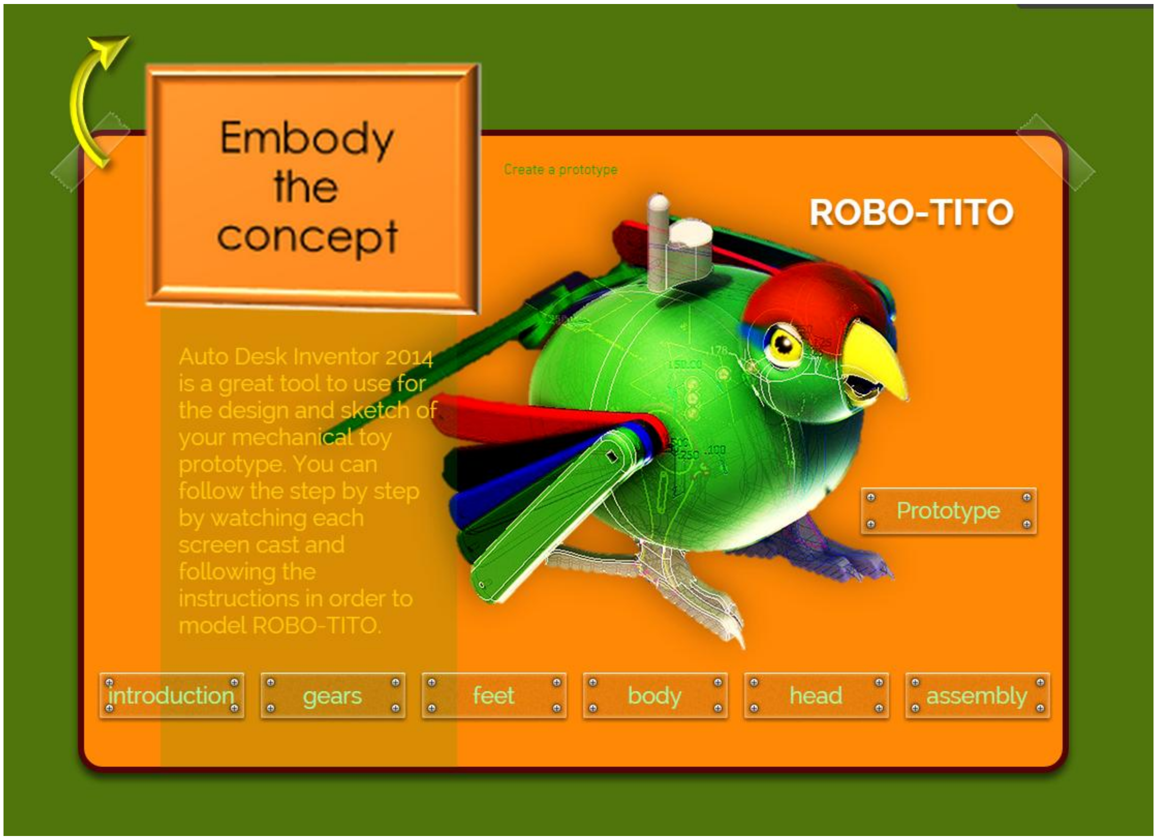

Figure 12. *ROBO-TITO*'s generate page from the Engineering Design Process, *Embody the Concept*. This stage of the Engineering Design Process module takes us to the Autodesk Screencast interactive videos.

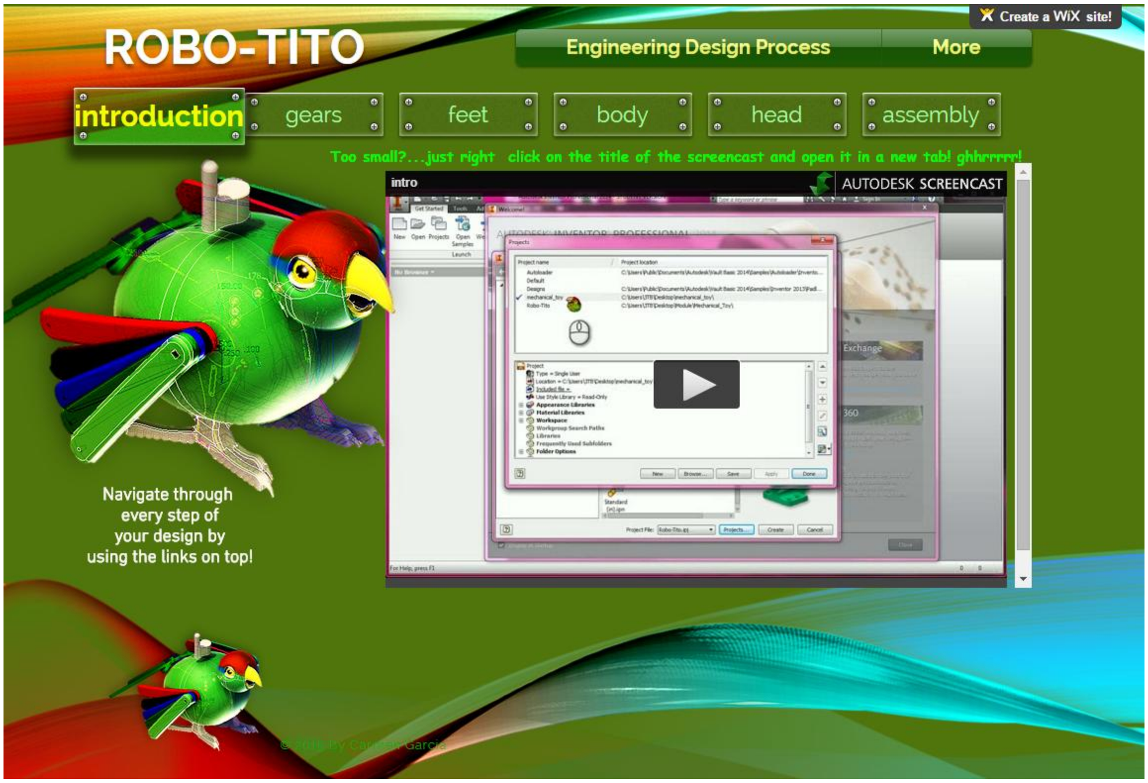

Figure 13. *ROBO-TITO*'s prototype page includes links to all the parts and assemblies and shows how to use Autodesk Inventor Pro 2014.

Figure 14. *ROBO-TITO*'s prototype page, Gears, includes all Autodesk Screencast tutorial videos to create all of the different size and types of gears. Feet, body, head, and assembly have the same interface, but they are in other pages to make it easier and accessible to the end user. Depending on the users' level of knowledge and skills, he or she can navigate to different sections or skip steps from the prototyping process.

Figure 15. *ROBO-TITO*'s test and evaluate process happens during Assembly when generating the concept. This occurs in Autodesk Inventor while prototyping the different parts, where they are tested to see if they work in the assembly. Inspections and analysis of interference are used while assembling the prototype.

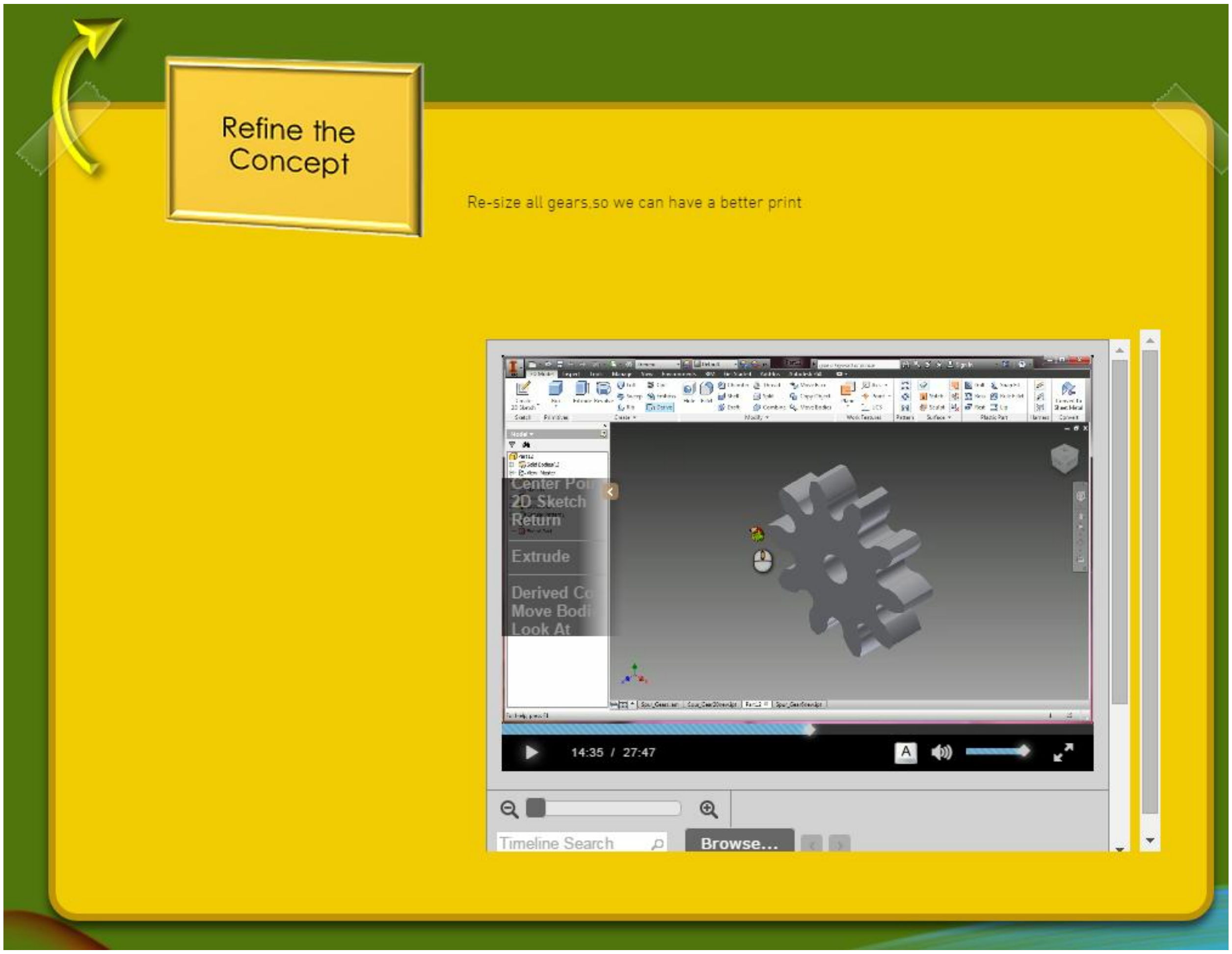

Figure 16. *ROBO-TITO*'s generate page from the engineering design process, Refine the Concept, shows a screencast tutorial video on how to manipulate and re-size gears and library parts in Autodesk Inventor by manipulating sketches.

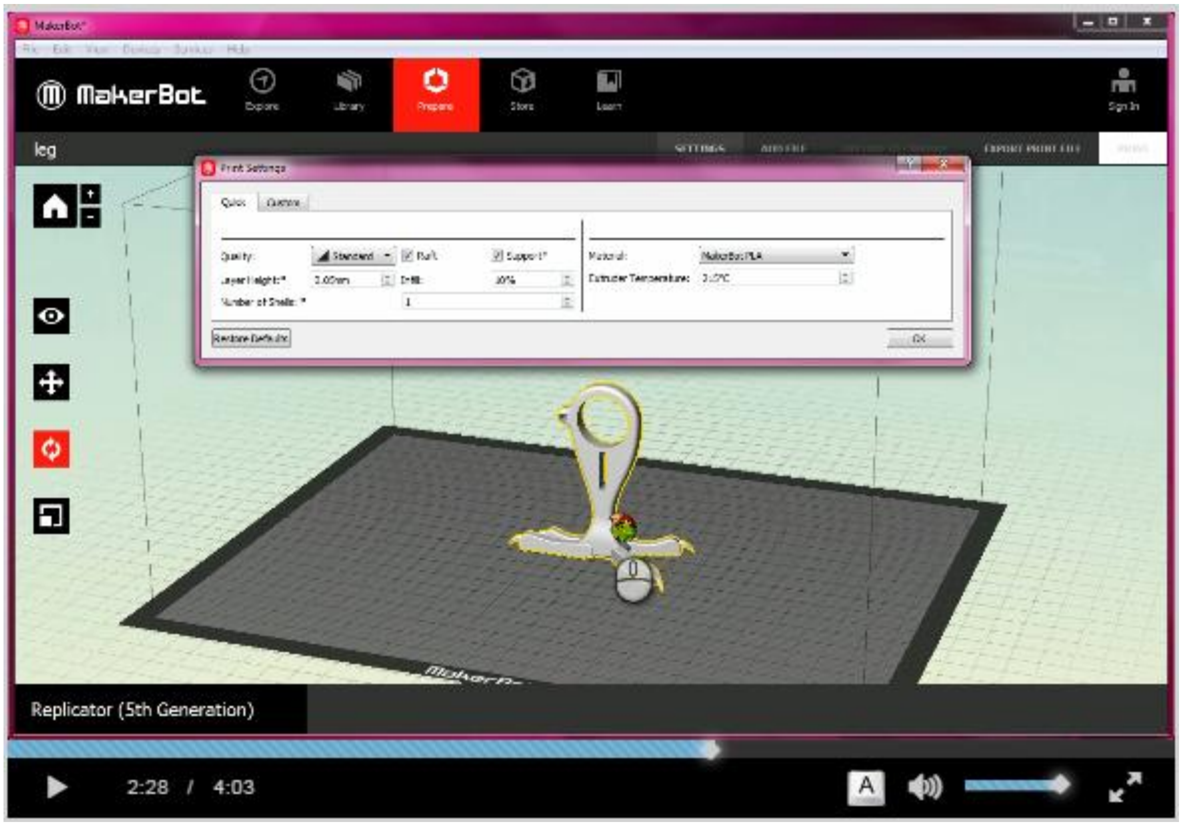

Figure 17. *ROBO-TITO*'s finalize page from the Engineering Design Process, Refine the Concept, deals with the final stage of the Engineering Design Process where users need to 3D print their *ROBO-TITO* mechanical toy. It contains a link to a page that has two screencasts of different 3D printing software. It shows how to scale a part and how to rotate it to make it easier for the 3D Printer to print.

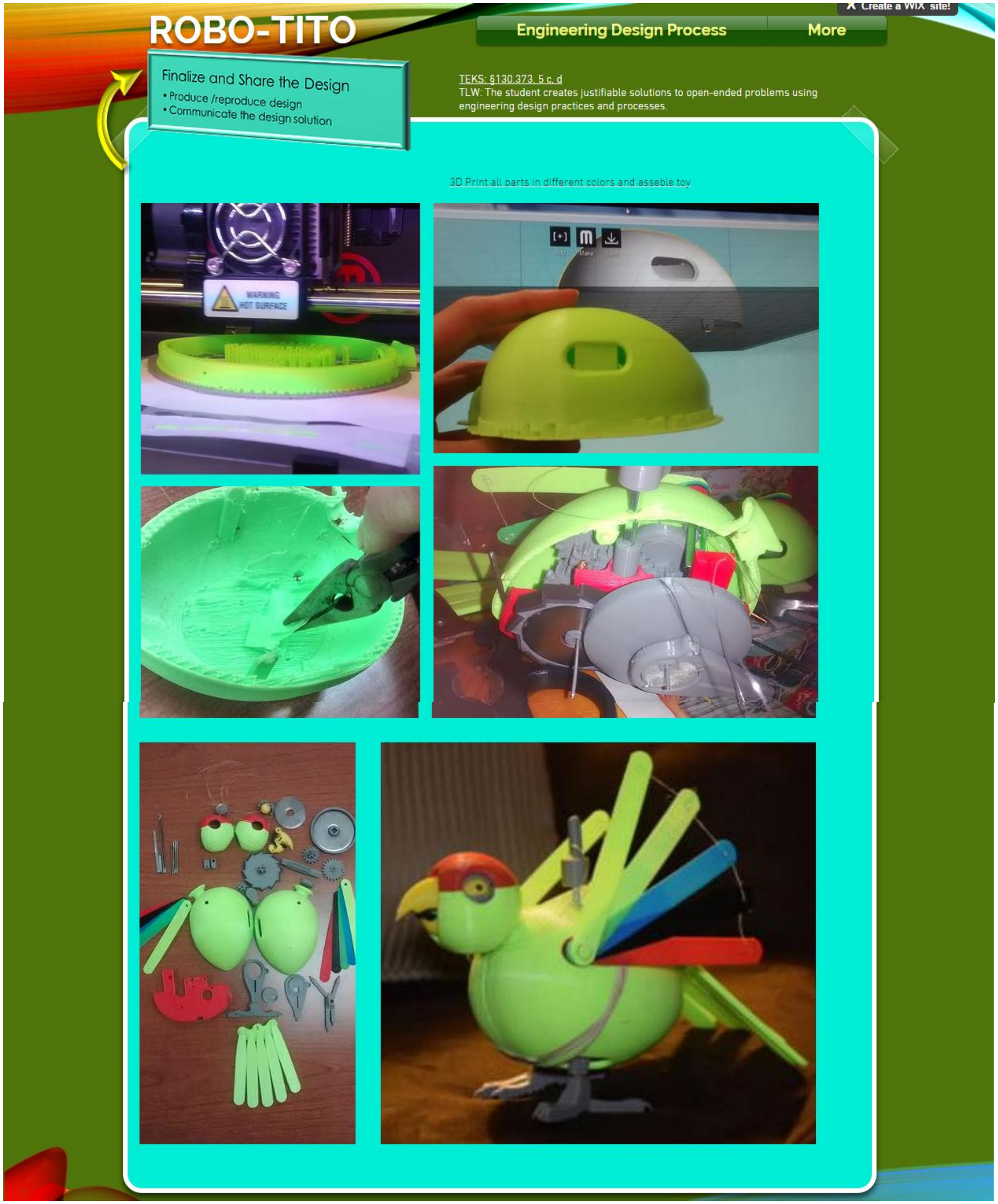

Figure 18. *ROBO-TITO*'s Finalize and Share the Design page contains pictures of the printed *ROBO-TITO* and how it was assembled physically.

Chapter 4: Module Evaluation and Results

This chapter describes an evaluation of the *ROBO-TITO* module. The module was evaluated at the Brownsville Early College High School, in Brownsville, TX. The study was approved with exempt status by the University of Texas at Austin Institutional Review Board (IRB) as protocol number 2015-02-0085. In the chapter the evaluation instrument is described and results are analyzed and discussed.

4.1 Module Evaluation Procedure

The module was evaluated in an Engineering Design and Presentation class over a period of three weeks. The students were enrolled previously in a robotics class during freshman year where, as a final project, they assembled a VEX robot and programmed it using Easy C v4 Cortex. Thus, the students had experience in working with robots.

After submitting all proper documentation to the University of Texas at Austin Institutional Review Board (IRB) and receiving approval from the Early College High School, parents, and students, I conducted the final stages of my research successfully. Informed consent was obtained from all participating students and their parents.

Some technical issues arose in the last week of the study when the server was down. Some students could not save their files in their folders, so they had to save them on the desktop of classroom computers instead. Otherwise the unit was implemented without difficulty.

The following equipment was used to implement the module:

- A drafting or digital imaging computer lab (two monitors per computer station) with Internet access and all the following software installed:
  - Autodesk Inventor Pro (2014 or 2016 versions)
  - MakerBot Replicator 2 or desire 3D printer software and drivers
  - Google Chrome
  - Access to http://carmen709.wix.com/robo-tito
- 3D MakerBot Replicator 2 Printer
- Headphones to work individually and/or speakers to work with the class

4.1.1 Sample Population Characteristics

Participating students were interested in engineering and were enrolled for the first time in an Engineering Design and Presentation class for the fall Semester 2015, and they volunteered to try out the module for a total 11.25 hours (three weeks in class in a block schedule of two sessions of 90 minutes and one session of 45 minutes per week) with no homework assigned. All students were from grade 10 and some were taking College Algebra as a dual enrollment class. All 38 students in the Engineering Design and Presentation class used the *ROBO-TITO* module, but only a random sample of 12 was selected for data collection and module evaluation purposes.

4.1.2 Evaluation Process

1. Students were given a Pre-Assessment/Survey about their knowledge of the Engineering Design Process and any skills they use in order to create a robot, product, or device.

2. Students were introduced to the *ROBO-TITO* module and were asked to read the instructions at http://carmen709.wix.com/robo-tito to become familiar with navigating the module.

3. The module was used as a class presentation tool and as a visual aid. Students were constantly challenged through the *inquiry process,* a teaching method that is based on questioning, to guide them to the correct answer without giving them the answers, to check for understanding and in order to see if they needed further assistance, or a quick explanation in other words.

4. Students were also asked to take Cornell Notes, a format of note taking that helps them to remember through repetition, during the entire process. They can use the notes for future reference when implementing the Engineering Design Process.

Here is the timeline and processes/lesson plan to evaluate the module during the nine sessions:

Week 1		
Day 1 (90 min) *TEKS: §130.373. 5: a* *TLW: identify and define an engineering problem.* **Essential Question (EQ)/Common Purpose Question (CPQ):** What is the Engineering Design Process and how does it work?	Day 2 (90 min) *TEKS: §130.373. 2: a, f, g; 5 c* **TLW:** *apply scientific processes and concepts outlined in the Texas Essential Knowledge and Skills (TEKS) for Biology, Chemistry, or Physics relevant to engineering design problems; determine the design parameters associated with an engineering problem such as materials, personnel, resources, funding, manufacturability, feasibility, and time* **EQ**: How to work with EDP Strategies and use them min real life?	Day 3 (45 min) *TEKS: §130.373. 3: b* *TLW: read and comprehend technical documents, including specifications and procedures* **EQ:** How to read and understand the EDP?

Table 3. Week 1 Lesson Plan for *ROBO-TITO* Module Study

Administer Pre-Assessment/Survey (10-15 minutes). Ask students to submit it as soon as they are done. Ask students to be prepared with paper and pen and write Cornell Notes during the entire study. Class Discussion: Ask students the essential question and give them a chance to respond what they know so far (≈3 minutes) Ask students to go to http://carmen709.wix.com/robo-tito and read the instructions on how to navigate the site. Let students click on the different links navigate through to site (≈5 minutes). *Note: Since YouTube is blocked at BISD for student accounts, students will need to wait until teacher plays videos, so we avoid students getting distracted by playing the videos at the beginning of the lesson.* Give a brief introduction to the module and the Engineering Design Process (≈10 minutes), and show how to navigate the module. Cover the first section of the Engineering Design Process using the *ROBO-TITO* module, show module videos, and emphasize on important vocabulary, inquiry students to check for understanding and listen for their ideas, and examples (≈50 min): **Identify the Need** **Describe the Need** *Remind students to take notes of main ideas and key vocabulary that they are not familiar with, and content we cover in class discussions.* Analyze Customer Needs Affinity analysis *t this point ask students to get in their notes part of the table as a sample.* Research existing approaches Identify constrains and requirements Define Performance Metrics Needs-Metrics Table *sk students to copy part of the table in their notes for future reference.* Review/Discussion: The last 10 minutes ask students what is the Engineering Design Process and why is it important to know what the customer needs, and answer any question students might have.	Before the bell rings, ask students to go to http://carmen709.wix.com/robo-tito and to be ready to continue with their Cornel Notes. **Warm-Up:** In the meantime everybody is ready, as a warmup exercise ask students to write the summary for their Cornell notes they took the first day by answering the EQ from Day 1 (First 5 minutes after the bell rings) Using the module go over basic formulas and engineering process to make students understand how they can be used in real life. Have students take Cornell Notes on formulas measurement conversions, and other needed mathematical equations and vocabulary they have not cover yet (10 minutes). Go over the following: **Characterize and Analyze the System** Understand relevant science and methods *Ask students to identify the different types of gears, ask them to demonstrate how they work, and make them explain. Class discussion (10 minutes). Ask students to write in their notes, the different gears they haven't learned about yet. To enrich the lesson, you might navigate away from module and search common mechanical machines that uses gears and show the picture and/or videos.* Identify critical subsystem design *Explain how the black box is used in the industry and ask the students to draw the Black Box in their notes (10 min).* Develop performance targets *Compare and contrast the performance metrics with the performance targets in a class discussion (3 minutes).* Develop Functional Models *Cover the importance of the activity diagram and the functional tree, and ask students to draw an example in their notes.* **Last 10 minutes of class:** Review high lights of Characterize and Analyze the System and quiz students orally on the different strategies that engineers use to understand the needed measurements and parameters.	Ask students to go to http://carmen709.wix.com/robo-tito and review the site to remember what they learned (5 minutes) and annotate their Cornell Notes, write questions, highlight main ideas, and do the necessary Cornell Notes repetitions (5 minutes). **Class Assignment:** Students must draw, label, and color the Engineering Design Process in a white sheet of paper, and write annotations of examples and name of strategies we have covered so far in each section.

Table 3, Cont.

Week 2		
Day 4 (90 min) *TEKS: §130.373. 5: e 3: a, b , c , d, e, and f* *TLW: identify or create alternative solutions to a problem using a variety of techniques such as brainstorming, reverse engineering, and researching engineered and natural solutions; communicate visually by sketching and creating technical drawings using established engineering graphic tools, techniques, and standards* **EQ:** How to generate concepts and make a decision?	Day 5 (90 min) *TEKS: §130.373. 3: a* *TLW: communicate visually by sketching and creating technical drawings using established engineering graphic tools, techniques, and standards* **EQ:** How to use Autodesk Inventor and how to use the Design Accelerator to create spur gears?	Day 6 (45 min) *TEKS: §130.373. 2: j* *TLW: use appropriate measurement systems, including customary and International System (SI) of units* **EQ:** How to use Autodesk Inventor and how to fix, or resize parts and sketches?
Check their Cornell Notes and their Engineering Design Process while the students open Autodesk Inventor and go to http://carmen709.wix.com/robo-tito. **Generate Concepts** Generate Ideas Brainstorm *Compare and contrast Brain Storm vs Mind Maps (10 minutes)* Mind Maps *Let the students play with bubbl.us to create their own Mind Map of the ROBO-TITO (10 minutes)* *Have the students draw their brainstorm and Mind Map sample on their notes.* C-Sketch Introduce the concept of C-Sketching to students and show the small sample from the module. Split students into six groups of 3 to 4 and have them create their own C-Sketch in a period of 30 minutes. Time them for the first 10 minutes, then for the last 20 minutes. Give students a different color so they can comment each other's design for 5 minutes each to a total of 15 minutes. Walk around and observe their designs. Once everybody was done commenting each other design, explain the designs from the module and how each one works. Some students might be surprised of how it works, but some student might come with clever ideas that were not even mentioned in the "Characterize and Analyze the System", so give them a chance to be creative and do not spoil their ideas	Start prototype from the module and watch the screencast from Prototype in the http://carmen709.wix.com/robo-tito to learn how to understand how the screencast works and how to set up a directory for Autodesk Inventor. Watch the More/Prototype/Gears/Spur Gear of 10 and pause it and follow the steps with the students to create a spur gear. *Note: If you save the project in in the server, it can be accessed from any computer, but if the server is down, you will not be able to access your files, nor you can save the changes.* Navigate through the Autodesk Inventor once you create and save the assembly as "Gears" Demonstrate how to orbit, how to pan, and how to zoom in and out slowly. You can constantly pause the video and rewind to play it again, or you can do it yourself so student can see it live. Create gear and edit settings from the browser bar. Explain every single step, and go back again and fix the size and edit it again, so student can see how easy is to maniple sizes and parameters in Inventor. Use basic inventor tools, and techniques to model spur gears	Create parts and assemble from the assembly mode Show students how to navigate in and out from a part to the assembly mode Ask students to continue editing the spur gear and to make a hole of .10 Model how to do it, and watch the video with the students

Table 4. Week 2 Lesson Plan for *ROBO-TITO* Module Study

until everybody is done. Select a Concept Ask students to put a star on their best design and show them how to use the Pugh Chart. Students must evaluate each other's design using the Pugh Chart then choose a winner. Walk around and ask students why they think is the design they choose their best design? *If there is time available ask them to present the winner selection and explain what features makes their design unique compared with what is provided in the module.* **Last 10 minutes**: check with the students which computers need to be updated to be used for Inventor, and make sure all of them work by next time. Ask students to see what version they have available and if they can open the same version in all of the computers.	Save all files before the class ends, and show files to students in the directory. Walk around and make sure students are not falling behind in their design; help the students that are some steps behind, and let students watch the video themselves to do it at their own pace. Last 5 minutes remind students to save their files, or to press Ctrl "S" periodically.	

Table 4, Cont.

Week 3		
Day 7 (90 min) *TEKS: §130.373. 3:a* *TLW: communicate visually by sketching and creating technical drawings using established engineering graphic tools, techniques, and standards* **EQ:** How to make changes of the design in inventor and test prototype parts?	Day 8 (90 min) *TEKS: §130.373. 5:f* TLW: test and evaluate proposed solutions using methods such as models, prototypes, mock-ups, simulations, critical design review, statistical analysis, or experiments **EQ:** How to test the design under the assembly mode in Autodesk Inventor, and 3D print a small part?	Day 9 (45 min) *TEKS: §130.373. 2: j, k* *TLW; use appropriate measurement systems, including customary and International System (SI) of units; use conversions between measurement systems to solve real-world problems.* **EQ:** What is the Engineering Design Process and how does it work?
Ask students to open their file in Autodesk Inventor and go to http://carmen709.wix.com/robo-tito. In the meantime the software opens, show in the screen the Engineering Design Process form the Module and ask students to be ready for a quick write. Quick Write (First 5 minutes): From the Engineering Design Process please describe the stages we cover so far and the strategies we learn in class? Identify Describe	Show students how to assemble all the gears and how to create a part within an assembly. Ask student to create a new assembly and to save it as toy, and to place the spur gear, a copy of the spur gear, and the two bevel gears. You can show the assembly video, but because of time constrain it is faster if you do it yourself.	Go to the 3D Print section in the http://carmen709.wix.com/robo-tito And show student ho to export and open .stl files to prepare them for 3D printing in MakerBot. Ask student to what percentage should the part be scaled to have its original dimension if the 3D printing software is only in millimeters. Let students use their conversion factors and

Table 5. Week 3 Lesson Plan for *ROBO-TITO* Module Study

Generate After students are done with quick write, ask students to exchange papers and read silently their answers, and write positive constructive comments on each other papers. Exchange papers twice or three times and time it. At the end ask for volunteers that would like to read out loud their answers and add to what they mention in their examples (10 minutes). To make students excited about the project: Explain students what happens in the **Embody the Concept** **Test and Evaluate the Concept** and **Redefine the Concept** by using the module's sections as a visual aid, then show the **Finalize and Share the Design** section in the module and show them the 3D printed *ROBO-TITO* parts, so they can identify the different gears and parts and observe the materials (10 minutes). Have students watch screencast to create and finish "Bevel Gears" (30 minutes) Once the students are done creating the bevel gears ask students to extrude a hole of .10 in in one bevel gear and to create cylinder on top of the other bevel gear with a square of 1/8". Try not to show them how to do it, make them figure it out themselves. Some students will be able to do it by themselves, if they finish with the task, ask them to help the other students that are still struggling, but ask them to use the inquiry process, and not to touch the mouse of their classmate at any point. The last 10 minutes request for everybody's attention and show them how to do it, and then let them do it. The last 5 minutes remind students to save their files.	Once everything is imported Ask students to create a box shaped frame with a hole of .10 a hole, some of them will be able to make it really quick because they already know how to sketch and how to extrude. Ask those students to help the other students that fall behind. Once that the hole is created, return to the assembly mode and start constraining the gears to the frame, and run an inspection analysis to see it the design does not have any intersections and it can run smoothly. After testing the gears and moving them in a way there is no more intersections, create another hole exactly in that position and constrain the gears. Preview animation with students, and let them try to constrain the gears themselves. Last 5 minutes: Remind student s to save their files Walk around and check to see if everybody was able to constrain the gears in opposite direction.	figure it out. Some students can do the math very quickly, ask them to explain how were they able to figure it out? *Due to lack of time, students will not be able to 3D print their saved part in class.* Conclusion: Review in a class discussion what we cover during the three weeks, and explain future possibilities and projects that could be accomplished with the knowledge acquired from the *ROBO-TITO* module. Administer Post Assessment/Survey the last 10 minutes

Table 5, Cont.

4.2 HYPOTHESIS AND TESTING

The hypothesis of the study is that using the module increases student understanding and likelihood of using the Engineering Design Process to design a product in the near future. To test this hypothesis a paired-sample t-test was performed between a Pre-Assessment/Survey and a Post-Assessment/Survey after the students were exposed to the module for three weeks. The survey measured the level of comfort on a five point scale, from Very Bad (1) to Very Good (5), with a score of 3 as Neutral. Table 6 shows the recorded results and calculations, and Table 7 the students' responses.

Survey	How proficient do you feel about the Engineering Design Process?		How good are you using computer software to solve problems?		How good are you with Autodesk Inventor?		How did you feel after creating your first product /robot/devise?		How good are your skills when designing a product/robot/devise?	
t test	p-value	0.0054594	p-value	0.070804	p-value	0.0128258	p-value	0.4627245	p-value	0.0960137
Student	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
1	3	3	1	3	2	3	3	3	3	3
2	3	4	3	4	3	4	4	3	3	4
3	3	3	3	2	2	3	5	3	3	2
4	3	4	4	4	3	4	3	3	3	3
5	3	4	1	3	1	3	1	2	2	3
6	3	5	3	5	3	4	3	5	3	5
7	3	3	3	2	3	2	3	5	3	3
8	3	3	2	4	3	4	4	4	4	4
9	4	4	4	4	3	4	5	5	4	4
10	3	4	4	4	3	3	3	3	3	4
11	4	5	4	4	4	4	5	5	4	5
12	3	5	3	4	3	3	3	4	3	3
Mean	3.17	3.92	2.92	3.58	2.75	3.42	3.50	3.75	3.17	3.58
Mean	Increase	0.75	Increase	0.66	Increase	0.67	Increase	0.25	Increase	0.41

Table 6. Pre and Post Assessment/Survey: Results with Mean and T-Test Calculations

Student	Have you learned a strategy/skill that helps you in the development/creation of a product/robot/devise? Explain.		If you were able to improve the way you create your product/robot/devise what do you think you will need to do?	
	Pre	Post	Pre	Post
1	"Yes, Last year I learned how to code a robot and how to program one. Other than designing and making my own robot, no I do not have prior knowledge."	"Yes, I have learned how to use Inventor to make gears for 3-D design printers"	"I would make it fun for everyone, sometimes it can be very boring doing the same thing over and over."	"Make the process more fun"
2	"Yes, I have used the program called east C V4 for Cortex to program a robot"	"Yes, I learned how to use Autodesk to create gears, bevel gears, and how to use the design process design."	"Learn how to code better to learn more about robots."	"I would keep editing my gears until they are perfect"
3	"Yes, We've learned about drafting and sketching"	"Yes, I learned how to use inventor"	discuss with group, think, design, plain sketch	"No, I don't"
4	"No, This is my first time using a software to develop something"	"Yes, I have learned some skills for example black box and to follow the Engineering Design Process. Also to always follow what the customer wants."	"I haven't built anything"	"I think I need some extra practice to make sure it comes out better than the one I am working out right now."
5	"How to design to proportions/measure and screw on items correctly"	"I learned how to use the black box a bit. I also learned how to extrude shapes in this program."	"Have a better design or sketch to have a great plan"	"Make sure my computer and the program I will be using will work the whole project. (no technical issues). Because that is what happened when I was trying to do the bevel gears."
6	"Yes, I have learned how to program a robot by using easy C."	"Yes, I have learned how to create gears in Inventor Autodesk Pro 2014. I also have learned more about the Engineering Design Process to help better design products."	"I will need to learn more ways/techniques to create products."	"I would have to listen to the steps more carefully. I would also have patience with the program."
7	"Yes, I have learned to program on easy C V4 for Cortex."	"I didn't have a program on my computer, so I had to look at their computer, but I knew what to do, the steps, and they didn't, so, ha!"	"I will need to improve on my application skills."	"I will have to need firsthand experience."
8	"Yes we learned how to make a robot make simple movements through the easy CV4 for cortex."	"I learned many skills through the Autodesk Inventor. I have learned to develop boxes, spheres, gears/bevel and spurs, and how to insert text. I am able to make a keychain through these skills."	"Learn more processes to make the robot more efficient and effective."	"Watch all the video is again to see what mistakes I had in the past. I would learn from my mistakes so that I could improve on crating the robot."
9	"Yes, We used Easy C for Cortex and it helped a lot"	"Yes, in this class with Ms. Garcia I learned how to do that I didn't even know that were possible."	"I think I will need to learn more ways and learn more with controls."	"I think I would need to improve my design by learning/consuming more information and/or asking

Table 7. Pre and Post Assessment/Survey: Students Quotes

				Mrs. Garcia to help me and check what needs improvement."
10	"Well one strategy would be the Engineering Design Process, as it deals with creating products and such efficiency and quality and reliability"	"Yeah, I learned a bunch of little techniques like how to sketch, extrude, constraint and change properties of gear."	"Find simpler ways to make something reliable and of good quality."	"Make a better working product were all of the gears are constrains and working properly. Oh, I might find an easier way to work and understand the program better"
11	"One of strategies that I learned was easy CV4 last year"	"Yes, I learned how make gears in Inventor Autodesk Pro 2014"	"I would like to learn program a little bit more to see how can I improve"	"I would like to save my gears!!! :(2014"
12	"No, I have not done any skills."	"Yes, I have learned some skills in creating a product/robot/devise. Some skills I have learned are making different gears, connecting gears and sketching things on gears."	"I have no idea what I should do to improve because I have never created my own product."	"If I were able to improve the way I created my product I would need to do is improve my skills in connecting gears and knowing how to make them faster."

Table 7, Cont.

4.3 ANALYSIS AND DISCUSSION

The study shows that overall there was an increase of knowledge and awareness of the Engineering Design Process after the *ROBO-TITO* module was introduced. As we can observe in Table 6, when students were asked “How proficient do you feel about the Engineering Design Process?” and “How good are you with Autodesk Inventor?”, there was a satisfactory increase in their perception after using the module. The t-test for paired samples, a two-tailed test, for those two questions shows that $p < 0.05$ which indicates that this is statically significant result, so we can reject the null hypothesis. Not only did the students acquire more knowledge about the Engineering Design process, but they also improved their skills at using Autodesk Inventor.

As per Table 7, students' responses indicate specific knowledge acquired. We can observe a trend toward positive responses in students' feedback overall on the Post-Assessment/Survey. For example, on the pre-survey, the response from student number 3 states that this student had previously not learned a strategy/skill that helps in the development/creation of a product/robot/device because this is the "first time using software to develop something". After the *ROBO-TITO* module, the response indicates that the student had learned "some skills [,] for example black box and follow the Engineering Design process. Also [learned] to always follow what the customer wants". Answers were overall positive and specific, but the majority mentioned Autodesk Inventor as their greater gain from this module. Student 4 suggests that in order to improve the process to create a product/robot/device the student should "watch all the [screencast] videos [from the *ROBO-TITO* module] again to see what mistakes…" the student made in the past; the student refers to mistakes made when modeling in Autodesk Inventor. Student 4 answers, "I would learn from my mistakes [,] so I could improve on creating a robot." In other words, student 4 will be using the module to learn more about how to improve future designs when creating a robot.

As observed during the study, students enjoy the 'generate' portion of the Engineering Design Process. Some students replied verbally that the part they like the most was when they created their C-Sketch and when they were able to make their own gears in Autodesk Inventor. Students were eager to use the software and to understand how it works; they became active learners and some of them even watched the screencast before I played it on the projector, so they could advance and figure out the next step and avoid getting stuck.

4.4 Pros and Cons

It was a great experience teaching the Engineering Design Process module, *ROBO-TITO*, and seeing the students' reactions and comments when watching the videos. One aspect that was meaningful was when students created their own C-Sketches with very little guidance from me; students saw a small sample (see Figure 10) from the module and from there, they created their own solutions. Students really thought about the design problem and were open-minded. One student included a hydraulic gear system that used inertia to create a continuous movement; others used chains even though they were not even mentioned in the entire module. During each technique presented from the Engineering Design Process, I paused and quizzed students verbally to check for understanding. The inquiry method of teaching really helped me determine if the students were paying attention, and/or understood the module. Asking students to take Cornell Notes during the entire module was a sagacious teaching strategy because the students were able to review what they learned and answer verbal quizzes accurately.

On two occasions the Engineering Design and Presentation teacher intervened during the initial stages of the module to give examples of his own to the students and enrich the lecture. I noted that this module could also be used in a class as a visual aid and the teacher can add his/her own experiences while presenting the key vocabulary covered in the module. When covering the black box myself with the students, I could not resist telling part of the story, "The Little Prince" by Antoine de Saint-Exupéry, and explaining how a drawing of a box contained the most beautiful sheep in the eyes of the Little Prince. I used this story with the students as an analogy when creating the black box in order to unleash students' imagination, though it caught my attention when I found out that students had not heard about this children's story. Even though they are teens, they were completely amused by the story.

It was an advantage to be able to stop the screencast and perform the steps myself along with the students when working with Autodesk Inventor. It gave me the opportunity to see and review the videos, and look at the module from the students' perspective.

On the other hand, watching the videos in front of the class made me feel self-aware of my voice and the tone I used when I made the videos; I felt awkward hearing myself in a recording in front of the students, so I lowered the volume at some points of the presentation, and I chose to explain the steps in a live presentation. Another aspect from the study that was not pleasant was the fact that there was a time constraint and I had to push the students to cover as much as possible in a short period of time, so speeding up the process to cover the *ROBO-TITO* module made the study less enjoyable. Due to the time constraints of the study, students were not able to 3D print their designed gears themselves as planned. To run the entire module and finish all stages of the Engineering Design Process will take approximately a whole semester. The 3D printing process is very slow; it will take more than the class time to finish it unless there is more than one printer available to print each student's designs.

4.4 STUDY CONCLUSIONS

Even though the module was implemented for only a few weeks, it demonstrated a statistically significant increase in students' awareness of the Engineering Design Process and the usage of Autodesk Inventor, a computer aided design program used in the engineering industry.

The Engineering Design Process module, *ROBO-TITO* is a successful tool to teach the Engineering Design Process in a hands-on, interactive, and modern way using the "do-it-yourself" technique. Students were enthusiastic about just creating gears in Autodesk Inventor and look forward to learning more and creating other designs themselves with their acquired knowledge. Letting the students watch the screencasts on their own during the study, and observing how they were able to figure out their own mistakes when modeling their gears, proved that the module really works. It was demonstrated that *ROBO-TITO* increases the awareness and understanding in the Engineering Design Process based on the t-test of the students' surveys. This indicates that *ROBO-TITO* can be successfully implemented in the Engineering Design and STEM classroom to teach the Engineering Design Process, or simply be used by anybody that wants to learn about it.

The making of *ROBO-TITO* increased my own learning about the Engineering Design Process and skills. It also improved my understanding of Autodesk Inventor significantly. I personally learned so much more about the Engineering Design Process with this project than what I had previously known. I understand the EDP now to the point that I can teach it to others.

Not only have I used the EDP to create the mechanical toy, but I applied the Engineering Design Process, techniques and skills in the making of the module itself. This study of the module is only part of the *Test and Evaluate the Concept* process that happens during the generate stage in the EDP. I applied all skills learned in the MASEE program and leaned above and beyond what I was expecting to learn. I discovered ways, techniques and resources that I would not have found myself if it were not for the use of all the intricate, yet essential, parts of the Engineering Design Process. I even (not intentionally) learned and discovered new tools and skills that I used for the first time ever, for example, how to create video tutorials with Autodesk Screencast and how to use wix.com, an HTML5 2.0 web tool. I gained first-hand experience repairing two popular 3D printers more than 20 times using Reverse Engineering techniques. I figured out different ways and techniques to 3D print more efficiently and effectively myself by “doing it”. The *ROBO-TITO* module has changed the perspectives I had about the Engineering Design Process in a positive way, and it has erased the boundaries between my imagination and reality.

Chapter 5: Conclusion and Future Work

5.1 Summary

This master's report explains the importance of the Engineering Design Process (EDP) and reviews how the *ROBO-TITO* module, a step-by-step self-paced and/or teacher-paced multimedia tutorial, helps students understand the EDP. The study analyzes current alternatives and practices used in introductory engineering programs that have in common students creating and learning through "do-it-yourself" and making discoveries by creating their own toys based on the constructivism theory. Also, the report demonstrates how *ROBO-TITO* addresses several Texas Essentials Knowledge and Skills from the Engineering Design and Problem Solving course as part of a project-based instruction hands-on module. Finally, results from a quantitative and qualitative evaluation indicate that *ROBO-TITO* increases students' understanding of the Engineering Design Process, indicating that it can be successfully implemented in the classroom.

5.2 Future Work

The *ROBO-TITO* module has room for improvement. Some iterations are needed to ensure the module results in a fully functional mechanical toy. Therefore there is still a design challenge that needs to be solved. The finished 3D printed mechanical toy itself did not work in real life due to inaccuracies of the printing process, such as the small bumps and defects on the PLA filament. Techniques like acetone smoothing and much more sanding to resize the parts could help with assembly, but a better design of the gearbox will be the best solution.

If the opportunity is presented, making these changes in the *ROBO-TITO* module with the Engineering Design class, and challenging the students to solve the design problem by creating a better gearbox for the *ROBO-TITO* module, will take the *ROBO-TITO* module to a higher level where students not only learn the Engineering Design Process, but use it and discover on their own. They could reverse engineer the product, thereby learning more engineering skills while solving the enigma and participating in the improvement of *ROBO-TITO* module themselves. Students can also create part of the module, and even record their own screencasts showing their findings and their solutions. Small competitions can be held, with the final *ROBO-TITO* designs posted in the module itself as a winner's prize and recognition. This experience would be more meaningful for all students if they participate in the design challenge themselves.

Also, the module could include different products and tutorials created by visitors and the community. It could include electrical engineering in order to create a robotic mechanical toy with more advanced capabilities. It would be possible to add different formats and use different CAD software besides Inventor, for example, Autodesk Fusion and SOLIDWORKS. The module could also be used by college students studying Engineering, with the addition of more advanced features like tolerances and accuracy analysis and other manufacturing processes such as injection molding. The module could include other tutorials on surface treatment techniques like using acetone to smooth the parts.

Other suggestions for the current module include:

- Include the teacher's login to create a class where students create accounts and take online assessments, so the teacher can see students' mastery of the EDP.
- Add site challenges and reviews that students must complete before moving to the next sections of the Engineering Design Process.
- Improve accessibility for users with disabilities.
- Include a blog to communicate and improve the module, and to ask questions.
- Changing language capabilities (e.g., translation into Spanish or other languages).
- Upload the module to social educational sites and resources like https://www.teachertube.com and the Autodesk Community.
- Target all of the TEKS of the Engineering Design and Problem Solving High School Course.

5.3 FUTURE PUBLISHING METHODS

Another change that might increase student engagement is to create an independently produced video game/app where students can design, create, test and send their files wirelessly to the 3D printer with the use of their smart devices. This new generation of teenagers spend more time on their phones and smart devices, including TV, while doing homework than ever before (Associated Press, 2015). It is imperative that as we advance in forms of media usage and platforms compatibility, education and the medium we use to teach must also progress in order to meet the needs of learners today, and to create a seamless learning and teaching process. A feature that could be adapted to the module as an app would be the use of 3D scanning and editing “on the spot” when performing a reverse engineering in a product, or improving a part design “just in time”.

Appendix A

§130.373. Engineering Design and Problem Solving (One Science Credit). (Texas Education Agency, 2010)

(a) General requirements. This course is recommended for students in Grades 11-12. Prerequisites: Geometry, Algebra II, Chemistry, and Physics.

(b) Introduction.

(1) Engineering design is the creative process of solving problems by identifying needs and then devising solutions. This solution may be a product, technique, structure, process, or many other things depending on the problem. Science aims to understand the natural world, while engineering seeks to shape this world to meet human needs and wants. Engineering design takes into consideration limiting factors or "design under constraint." Various engineering disciplines address a broad spectrum of design problems using specific concepts from the sciences and mathematics to derive a solution. The design process and problem solving are inherent to all engineering disciplines.

(2) Engineering Design and Problem Solving reinforces and integrates skills learned in previous mathematics and science courses. This course emphasizes solving problems, moving from well defined toward more open ended, with real-world application. Students apply critical-thinking skills to justify a solution from multiple design options. Additionally, the course promotes interest in and understanding of career opportunities in engineering.

(3) This course is intended to stimulate students' ingenuity, intellectual talents, and practical skills in devising solutions to engineering design problems. Students use the engineering design process cycle to investigate, design, plan, create, and evaluate solutions. At the same time, this course fosters awareness of the social and ethical implications of technological development.

(c) Knowledge and skills.

(1) The student, for at least 40% of instructional time, conducts engineering field and laboratory activities using safe, environmentally appropriate, and ethical practices. The student is expected to:

(A) demonstrate safe practices during engineering field and laboratory activities; and

(B) make informed choices in the use and conservation of resources, recycling of materials, and the safe and legal disposal of materials.

(2) The student applies knowledge of science and mathematics and the tools of technology to solve engineering design problems. The student is expected to:

(A) apply scientific processes and concepts outlined in the Texas Essential Knowledge and Skills (TEKS) for Biology, Chemistry, or Physics relevant to engineering design problems;

(B) apply concepts, procedures, and functions outlined in the TEKS for Algebra I, Geometry, and Algebra II relevant to engineering design problems;

(C) select appropriate mathematical models to develop solutions to engineering design problems;

(D) integrate advanced mathematics and science skills as necessary to develop solutions to engineering design problems;

(E) judge the reasonableness of mathematical models and solutions;

(F) investigate and apply relevant chemical, mechanical, biological, electrical, and physical properties of materials to engineering design problems;

(G) identify the inputs, processes, outputs, control, and feedback associated with open and closed systems;

(H) describe the difference between open-loop and closed-loop control systems;

(I) make measurements and specify tolerances with minimum necessary accuracy and precision;

(J) use appropriate measurement systems, including customary and International System (SI) of units; and

(K) use conversions between measurement systems to solve real-world problems.

(3) The student communicates through written documents, presentations, and graphic representations using the tools and techniques of professional engineers. The student is expected to:

(A) communicate visually by sketching and creating technical drawings using established engineering graphic tools, techniques, and standards;

(B) read and comprehend technical documents, including specifications and procedures;

(C) prepare written documents such as memorandums, emails, design proposals, procedural directions, letters, and technical reports using the formatting and terminology conventions of technical documentation;

(D) organize information for visual display and analysis using appropriate formats for various audiences, including, but not limited to, graphs and tables;

(E) evaluate the quality and relevance of sources and cite appropriately; and

(F) defend a design solution in a presentation.

(4) The student recognizes the history, development, and practices of the engineering professions. The student is expected to:

(A) identify and describe career options, working conditions, earnings, and educational requirements of various engineering disciplines such as those listed by the Texas Board of Professional Engineers;

(B) recognize that engineers are guided by established codes emphasizing high ethical standards;

(C) explore the differences, similarities, and interactions among engineers, scientists, and mathematicians;

(D) describe how technology has evolved in the field of engineering and consider how it will continue to be a useful tool in solving engineering problems;

(E) discuss the history and importance of engineering innovation on the United States economy and quality of life; and

(F) describe the importance of patents and the protection of intellectual property rights.

(5) The student creates justifiable solutions to open-ended problems using engineering design practices and processes. The student is expected to:

(A) identify and define an engineering problem;

(B) formulate goals, objectives, and requirements to solve an engineering problem;

(C) determine the design parameters associated with an engineering problem such as materials, personnel, resources, funding, manufacturability, feasibility, and time;

(D) establish and evaluate constraints pertaining to a problem, including, but not limited to, health, safety, social, environmental, ethical, political, regulatory, and legal;

(E) identify or create alternative solutions to a problem using a variety of techniques such as brainstorming, reverse engineering, and researching engineered and natural solutions;

(F) test and evaluate proposed solutions using methods such as models, prototypes, mock-ups, simulations, critical design review, statistical analysis, or experiments;

(G) apply structured techniques to select and justify a preferred solution to a problem such as a decision tree, design matrix, or cost-benefit analysis;

(H) predict performance, failure modes, and reliability of a design solution; and

(I) prepare a project report that clearly documents the designs, decisions, and activities during each phase of the engineering design process.

(6) The student manages an engineering design project. The student is expected to:

(A) participate in the design and implementation of a real or simulated engineering project;

(B) develop a plan and timeline for completion of a project;

(C) work in teams and share responsibilities, acknowledging, encouraging, and valuing contributions of all team members;

(D) compare and contrast the roles of a team leader and other team responsibilities;

(E) identify and manage the resources needed to complete a project;

(F) use a budget to determine effective strategies to meet cost constraints;

(G) create a risk assessment for an engineering design project;

(H) analyze and critique the results of an engineering design project; and

(I) maintain an engineering notebook that chronicles work such as ideas, concepts, inventions, sketches, and experiments.

Source: The provisions of this §130.373 adopted to be effective August 23, 2010, 34 TexReg 5941.

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VITA

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